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ORIGINAL ARTICLE

# Roles of researchers in inter- and transdisciplinary sustainability research: a reflection tool

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## Abstract

Inter- and transdisciplinary (ITD) research is increasingly called for and supported to promote sustainable transformation through knowledge co-production, knowledge integration, and solution development. The paper explores what is needed to support researchers in reflecting on their new roles in ITD research. We introduce a reflection tool that makes the growing literature on researchers' roles in sustainability science applicable to ITD projects. Its design is based on the arguments that each researcher can have several roles within one research project and that focusing on a few key roles increases clarity compared to differentiating many specialized roles. The tool consists of (1) a researcher survey that operationalizes six prominent roles (traditional scientist, self-reflexive scientist, knowledge integrator, knowledge broker, process facilitator, and change agent), (2) a visualization of role profiles from the survey, and (3) a set of reflection questions on related opportunities, challenges, and coping strategies on individual and project level. We empirically applied the tool in two ITD research projects focused on sustainable food production and water and forest ecosystem management. Comparative application of the tool yielded diverse role profiles of researchers in both projects, with different patterns for senior and junior researchers as well as natural and social scientists. The reflection produced a collection of opportunities, challenges, and coping strategies that corroborates and extends insights from ITD literature. We discuss how the tool triggers multi-dimensional reflection on roles (individual and project level, role combinations, self-perception and external perception) and outline opportunities for further strengthening such reflection in ITD research.

**Keywords** Roles of researchers · Tool · Inter- and transdisciplinary research · Sustainability science · Operationalization · Reflection

## Introduction

The increasingly recognized need for sustainable transformation in many parts of society has given rise to new forms of science and knowledge production (Schoolman et al. 2012; Lang et al. 2012; Fazey et al. 2018; Norström et al. 2020; Caniglia et al. 2021). One of these forms is inter- and transdisciplinary (ITD) research that has been called for increasingly, among others, by "[p]olicymakers on the European and national levels, funding agencies, and many academic institutions" (Felt 2022, p. 204; cf. Glänzel and Debackere 2022). ITD research enables researchers from different disciplines as well as stakeholders from policy and practice to grasp the complexity of sustainability problems by crossing the boundary between their different values, concepts, and perspectives (Nurius and Kemp 2019; Pohl et al. 2021; Hoffmann et al. 2022). Core aspects of ITD research are knowledge co-production, knowledge

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integration, and solution orientation (Lang et al. 2012; Miller et al. 2014; Hoffmann et al. 2017a). Knowledge integration refers to "a process of combining a wide range of perspectives from different disciplines (i.e., interdisciplinary integration), as well as from research, policy, and practice (i.e., transdisciplinary integration)" (Hoffmann et al. 2022, p. 2) and to its outputs (O'Rourke et al. 2016). Knowledge co-production denotes "iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future" (Norström et al. 2020, p. 183). Solution-oriented research in the field of sustainability "investigates actions and practices… that are intended to advance sustainable development" (Lang and Wiek 2022, p. 31).

A precondition for successful knowledge integration, knowledge co-production, and solution development is that researchers (and stakeholders) move beyond their traditional roles and take on new and/or different roles within the ITD team. Such new roles are usually shaped by contextual conditions and either adopted purposefully ('role-taking') or gradually in an interplay of the integration, co-production, and solution context and the personal qualities and competencies of researchers and stakeholders ('role-making') (Hilger et al. 2021; Hoffmann et al. 2024). They are not static and may change over time (Huning et al. 2021; Arnold 2022). Some of the roles, such as 'traditional scientist' align well with the roles researchers generally adopt, while others like 'knowledge broker' or 'change agent' transcend existing roles (Hoffmann et al. 2024). Being aware of the existence of these different roles in ITD teams helps to make their own and others' expectations about the different roles transparent (Bulten et al. 2021; Hilger et al. 2021). This, in turn, can help to address or prevent potential challenges or conflicts arising from certain roles or role combinations (Hilger et al. 2021). Further, it can scale down expectations that individual researchers and stakeholders need to perform all roles to co-produce and integrate new knowledge and develop solutions (Hilger et al. 2021). Therefore, it is important that researchers of ITD teams reflect on their roles and the challenges and opportunities they entail.

In this paper, we explore what is needed to support researchers in making use of the growing literature on the roles they can and do play in ITD research projects. We argue that, for making this body of knowledge relevant for the practice of sustainability science, researchers from various fields need to be enabled to understand and reflect on roles in a simple, accessible, and time-efficient manner. More specifically, we see five objectives for enhanced reflection: (1) foster researchers' individual awareness of their own roles; (2) explore the relationship between researchers' different roles in terms of opportunities, challenges, and coping strategies; (3) enable an exchange between their own and external perceptions of researchers' roles within a team; (4) map the combination of researchers' roles on the project level; and (5) spark discussion about how well this combination of roles aligns with the project goals. These five objectives have guided us in the development of a reflection tool that could be integrated into existing toolkits for ITD research (cf. Laursen et al. 2024). The reflection tool is anchored in the literature on researchers' roles, notably in debates about whether researchers can have only one or different roles within an ITD project (e.g., Pielke 2007; Crouzat et al. 2018; Bulten et al. 2021) and about the number and granularity of roles that should be differentiated (e.g., Wittmayer and Schäpke 2014; Horlings et al. 2020; Bulten et al. 2021; Hilger et al. 2021). Our aim was to design a tool that reaches the five objectives for enhanced reflection while being sufficiently parsimonious for application across a wide range of ITD research projects.

The paper is structured as follows: first, we review major theoretical perspectives on roles of researchers and justify the design choices of our reflection tool. Second, we describe the tool's method and its empirical application in two ITD research projects. Third, we present the data obtained from this application, highlighting what preliminary role patterns, opportunities, challenges, and coping strategies emerged. Fourth, we discuss our results against the backdrop of ITD literature and with a focus on the tool's contribution to the broader knowledge base. Fifth, we conclude with ideas on how to further advance reflection on researchers' roles in ITD research.

## Theory

### Perspectives on the roles of researchers

The roles of researchers have received increasing attention in the scholarly literature in recent years. Many scholars have outlined different ideal–typical roles that researchers can or should take on when conducting ITD research and described specific activities related to these roles (e.g., Pohl et al. 2010; Wittmayer and Schäpke 2014; Adelle et al. 2020; Bulten et al. 2021; Hilger et al. 2021; Kruijf et al. 2022; Hoffmann et al. 2022; Schrage et al. 2023). As research on transformations combines questions of 'what is' and 'what ought to be' and devotes particular attention to 'what can be' (Avelino and Grin 2017), the spectrum of potential roles in this field is broad, encompassing analytical, pragmatic, as well as normative orientations. While tools exist to reflect on research stances (Hazard et al. 2020) and to explore identities of researchers (Temper et al. 2019), we argue that there is still a lack of an easily applicable tool that allows for mapping the roles of researchers in ITD research and reflecting on opportunities and challenges that these role profiles entail on individual and project level. Such reflection is important as it can support a reflexive approach to the position of sustainability science (e.g., inquiries into values and desirable futures) (Miller et al. 2014; Fazey et al. 2018), shed light on links between researchers' roles and goals of ITD research (e.g., solution-oriented and process-first projects) (Miller 2013; Miller et al. 2014; Lang and Wiek 2022), and problematize external constraints for certain roles (e.g., in terms of institutional structures and career prospects) (Miller et al. 2011; Guimarães et al. 2019).

The literature provides different entry points for reflection on researchers' roles. One debate is whether researchers need to decide for a single role or can play multiple roles within the duration and context of one research project. Pielke (2007) assumes that researchers need to choose from the four mutually exclusive roles of pure scientist, science arbiter, honest broker of policy alternatives, and issue advocate, even though roles may change throughout a career. Scholars have mapped this distinction on a role continuum (Donner 2014) and differentiated the range of possible roles further, but maintained the idea that researchers need to choose one role (Crouzat et al. 2018, pp. 99–103). The value of this conceptualization lies in its parsimony and its ability to trigger debate about the relationship between science and advocacy. By contrast, another strand of literature argues that roles can be combined (Huning et al. 2021), even though tensions may arise between certain roles (Wittmayer and Schäpke 2014; Arnold 2022). Bulten et al. (2021) study the relationship between role combinations on the level of individual researchers. They find that while most roles are compatible or mutually supportive, certain combinations are problematic. For example, they find that the role of a transition leader clashes with the roles of traditional and self-reflexive scientists; and the process facilitator role conflicts with the traditional researcher role, too (Bulten et al. 2021, p. 1278). Research has shown that even rather different boundary-spanning roles, such as science arbiter, honest broker of policy alternatives, and issue advocate, can be combined by the same researchers in the same process (Sarkki et al. 2020). Likewise, the repertoires of some allegedly "new" knowledge brokering roles are surprisingly aligned with more "traditional" roles of scientists (Turnhout et al. 2013).

Another relevant debate is about how many different role profiles are needed to adequately capture the different activities of researchers. There is one part of the literature that focuses on further differentiating researchers' roles into ever more fine-grained profiles. One example is Hilger et al. (2021) who identified 15 roles that researchers and practitioners take on. Through this detailed analysis, the authors show "the breadth of activities" (Hilger et al. 2021, p. 2064) that characterizes transdisciplinary sustainability research. Scholars have developed even more fine-grained typologies for specific roles, such as different types of transition intermediaries (Kivimaa et al. 2019), roles of researchers in collaborative governance interventions (Peltola et al. 2023), different profiles in knowledge transfer (Thompson et al. 2006), and various types of transformative and activist researchers (Temper et al. 2019). Another part of the literature describes a more limited number of researchers' roles (Pohl et al. 2010; Wittmayer and Schäpke 2014; Horlings et al. 2020; Bulten et al. 2021). Several well-known role labels, such as self-reflexive scientist or change agent, have emerged from this literature and serve as focal points for identity formation among sustainability scientists.

## Towards a reflection tool

The two debates inform the basic design of a tool for fostering reflection about researchers' roles in ITD projects. We hold that an approach that allows for role combinations is most conducive to reflection. While some researchers may identify primarily with one specific role, typologies with mutually exclusive roles are too simplistic as they disregard the possibility of playing multiple roles within one research project. First, they paint with a broad brush over the diversity of roles found in scientific practice, ignoring, for instance, different degrees of reflexivity in scientists' work (Popa et al. 2015). Second, their preference for honest brokerage neglects that there is a wider spectrum of roles available for scientists who engage with society, including, for example, the facilitation of processes that empower stakeholders to participate in knowledge co-production and co-learning (Roux et al. 2017). Third, their notion of mutually exclusive roles clashes with the reality of many sustainability researchers, which is characterized by their desire—and societal expectations—to contribute to both scientific progress and societal problem-solving (Wittmayer et al. 2017; Fazey et al. 2018). The approach we adopt pays greater attention to the diversity of roles within science and in its engagement with societal stakeholders, is open for incorporating new roles that complement existing roles (e.g., knowledge integration on top of traditional science), and takes into account that sustainability researchers often need to combine roles to create academic and societal impact. Indeed, researchers need to take on a diversity of tasks in different project phases (Stauffacher et al. 2008), resulting in distinct personal journeys within ITD projects (McGowan et al. 2014). Thus, a tool that helps to reflect on various roles that researchers play will have to go beyond a simple continuum.

We further argue that a limited number of roles is best suited for reflection. Fine-grained role differentiation may be useful for understanding specific processes, such as knowledge transfer and uptake in governance interventions and transitions, but is likely too complex for fostering reflection for three reasons. First, a small number of easily understandable and applicable role descriptions supports reflection even among researchers who are unfamiliar with the different ideal–typical roles described in the literature. Second, some of the numerous roles described in the literature overlap in their activities (e.g., 'knowledge collector' and 'scientific analyst' in Hilger et al. 2021) and/or are located in similar places at interfaces of science and policy or practice (e.g., "intermediary", "knowledge broker", and "expert in learning" in Kruijf et al. 2022, p. 398). Third, we argue that facilitation of "expectation management, mutual transparency, and clarity of roles" (Hilger et al. 2021, p. 2066) is better achieved through conceptual parsimony rather than complexity. Bringing the debates about the number and compatibility of roles together, we decided that our reflection tool should do two things: it should allow for a certain complexity by capturing multiple roles that researchers can play over the course of one research project, but limit complexity regarding the number of potential roles covered.

Our tool covers six different roles that researchers can assume within an ITD project team based on existing typologies and descriptions in the literature (Pohl et al. 2010; Wittmayer and Schäpke 2014; Hilger et al. 2018, 2021; Adelle et al. 2020; Bulten et al. 2021; Hoffmann et al. 2022): traditional scientist, self-reflexive scientist, knowledge integrator, knowledge broker, process facilitator, and change agent (see Table 1). Drawing on this literature, we define the roles as follows (cf. Salomon 2023).[1] The traditional scientist is a scientist who deconstructs complex problems and systematically analyzes and communicates them in an intersubjective way. A self-reflexive scientist observes and critically reflects on research practices, power dynamics, and his/her and the team's normative orientation. A knowledge integrator uses integrative methods to bridge different perspectives from different disciplines and fields, leading to new integrated knowledge, and assesses and evaluates these processes and the resulting outputs. A knowledge broker identifies and connects relevant actors from science, policy, and practice and adapts and tailors different types of knowledge to specific target audiences. A process facilitator designs the learning process (e.g., by organizing workshops), provides space for critical reflection, and condenses the outcomes. Finally, a change agent strategically networks with actors from science, policy, and practice in the context of change processes by, for example, coaching and advising actors from policy and practice, motivating them to lead change processes, and facilitating and participating in such processes (cf. Miller 2013).

We agree that having multiple, overlapping, or changing roles within a project can lead researchers to "experience tensions between different roles" (Bulten et al. 2021, p. 1279). Such tensions and potential incompatibilities, however, are a matter for empirical investigation rather than conceptual pre-definition. The same applies to the potentially diverse tasks that researchers adopt. For instance, the role of critical scholars may combine tasks from across the roles of self-reflexive scientists (e.g., critically reflect on power dynamics), knowledge integrators (e.g., bridge boundaries of different disciplines or fields), and process facilitators (e.g., provide space for critical reflection and deliberation). Thus, while the role labels provide some orientation, the individual combination of tasks should serve as basis for reflection.

## Method and materials

### Tool design

The reflection tool consists of a role survey for individual researchers, a spider web graph for immediate role visualization on the individual and project level, and a set of questions for individual and project team reflections. All these elements can be implemented in a workshop setting of around one hour. Drawing on existing role descriptions, the role survey operationalizes each of the six roles that we focus on in the form of three typical tasks (see Table 1). A researcher filling out the survey decides for each task whether she/he performs this task in the context of the specific ITD project (assigning it a score of 1) or not (assigning it a score of 0). From these responses, a simple additive score ranging from 0 (= role not assumed) to 3 (= role fully assumed) is calculated. The rationale behind equal weighting of tasks is that any ranking would imply valorizing certain ways of doing research more than others, which we think is not in line with the pluralist community of sustainability science. Once aggregated, the scores for all six roles are transferred into a spider web graph to obtain the individual role profile of the researcher (see Supplementary Material). The reason for choosing a spider web is that it is neutral with respect to combinations of roles. It allows for wearing different hats at the same time, a possibility that has been stressed by other authors but is not well reflected in their tools using one or two axes to map researchers' roles (cf. Schrage et al. 2023). It also mirrors our position that (in-)compatibilities of different roles should be a subject of empirical inquiry rather than conceptual decision. The individual role profiles can be laid on top of each other in a project-level spider web graph to see which roles are most strongly present within the team and which ones are less represented. A set of questions for individual and project team reflection helps discussing the results (cf. Temper

[1] The role reflection tool was developed by Benjamin Hofmann and Sabine Hoffmann (with comments by Rea Pärli) and used by Hanna Salomon, amongst others, during her master's thesis. Parts of this paper are based on findings presented in Hanna Salomon's master's thesis.

**Table 1** Operationalization of six roles of researchers in ITD projects

| Role | | Activities/tasks | Example of conducting activity/task | Adapted from |
|---|---|---|---|---|
| 1 | Traditional scientist | Deconstruct complex problems into solvable parts | Apply scientific concepts and theories | Adelle et al. (2020, p. 58) and Bulten et al. (2021, p. 1273) |
| | | Conduct or supervise the conduct of systematic analyses of deconstructed problems and potential solutions | Use quantitative and/or qualitative methods | Bulten et al. (2021, p. 1273), Pohl et al. (2010, p. 277) and Wittmayer and Schäpke (2014, p. 488) |
| | | Communicate scientific knowledge validated as intersubjective/objective by the respective discipline | Write peer-reviewed scientific publications, give presentations at scientific conferences | Bulten et al. (2021, p. 1273) and Pohl et al. (2010, p. 276) |
| 2 | Self-reflexive scientist | Observe and reflect on research practices | Write observation protocols or keep research diaries | Bulten et al. (2021, p. 1273) and Hilger et al. (2018, p. 143) |
| | | Critically reflect on internal and external power dynamics that shape the project | Identify hierarchies and differences in resource endowment | Bulten et al. (2021, p. 1273) and Wittmayer and Schäpke (2014, pp. 488–489) |
| | | Critically reflect on own normative orientation in relation to project goals | Reflect on own personal motivations, attitudes, and policy preferences | Bulten et al. (2021, p. 1273) and Wittmayer and Schäpke (2014, pp. 488–489) |
| 3 | Knowledge integrator | Cross or bridge boundaries of different disciplines or fields | Link theoretical concepts from different disciplines or fields, co-create integrative frameworks, or develop interdisciplinary methods | Hoffmann et al. (2022, p. 3) |
| | | Synthesize knowledge from different disciplines or fields and generate new integrated knowledge | Recognize critical connections and leverage potential synergies | Hoffmann et al. (2017b, p. 680) and Hoffmann et al. (2022, p. 3) |
| | | Design, plan, monitor, assess, and evaluate integrative processes and their integrated outputs | Develop a shared vision for integration, defining who contributes what, at which stage, for which purpose, and supported by which methods and procedures | Hoffmann et al. (2017b, p. 690) and Hoffmann et al. (2022, p. 3) |
| 4 | Knowledge broker | Identify and connect relevant actors from science, policy, practice, and/or the public | Map the actor landscape, identify, and mediate different perspectives | Adelle et al. (2020, p. 58), Bulten et al. (2021, p. 1273) and Wittmayer and Schäpke (2014, p. 488) |
| | | Bridge different types of knowledge | Make scientific knowledge usable for different target audiences and/or integrate knowledge from policy, practice, and/or the public into the scientific process | Bulten et al. (2021, p. 1273), Turnhout et al. (2013, pp. 358; 361–362) and Juhola et al. (2024, p. 6) |
| | | Translate, interpret, adapt, and tailor different types of knowledge to different target audiences | Find feasible problem–solution couplings | Adelle et al. (2020, p. 58) and Bulten et al. (2021, p. 1273) |
| 5 | Process facilitator | Initiate and facilitate learning processes or experiments within project team and/or with actors from policy, practice, and/or the public | Develop tools to jointly reflect on researchers' roles and/or integration in the project | Bulten et al. (2021, p. 1273), Wittmayer and Schäpke (2014, pp. 488–489) and Pohl et al. (2010, p. 277) |
| | | Organize and prepare workshops, select and invite actors (from science, policy, practice, and/or the public), and condense the outcomes | Design workshops to develop action options and analyze implications of these options for sustainability transformations | Bulten et al. (2021, p. 1273), Adelle et al. (2020, p. 58) and Wittmayer and Schäpke (2014, p. 488) |
| | | Provide space for critical reflection and deliberation | Encourage expression of different viewpoints | Hilger et al. (2021, p. 2056) and Pohl et al. (2010, p. 277) |

**Table 1** (continued)

| Role | | Activities/tasks | Example of conducting activity/task | Adapted from |
|---|---|---|---|---|
| 6 | Change agent | Strategically network with actors from science, policy, practice, and/or the public in the context of change processes | Engage with actors' concerns and generate possible solutions for real-world problems | Wittmayer and Schäpke (2014, pp. 488–489) |
| | | Intervene into policy, practice, and/or the public with the aim to contribute to change processes | Engage in policy consultations and in innovation processes in relation to practices, contribute to reconfiguration of actor relations | Bulten et al. (2021, p. 1273) and Hilger et al. (2018, p. 143) |
| | | Empower actors from policy, practice, and/or the public to lead own change processes | Make use of motivation and capacity-building tools | Wittmayer and Schäpke (2014, pp. 488–489), Bulten et al. (2021, p. 1273) and Adelle et al. (2020, p. 58) |

Compiled by the authors; sources indicated in table

et al. 2019, p. 5), notably opportunities and challenges of different role combinations, potential coping strategies on the individual level (Bulten et al. 2021, pp. 1280–1281), and the alignment of roles performed by the team with the project goals (Table 2). Our incorporation of the project level goes beyond the focus on individual reflection in the existing literature (cf. Kruijf et al. 2022; Schrage et al. 2023).

## Project context

We applied the tool in two ITD research projects in the area of sustainability. The project "Transformation in Pesticide Governance" (TRAPEGO) explores the potential for an evidence-based sustainable transformation of agricultural pesticide policy and practice (cf. Hofmann et al. 2023). It employs an ITD approach to understand the preferences and interactions of different policy and practice actors in an area of "societal, economic, and environmental trade-offs" (Ingold et al. 2024). The project "Transformation Toward Resilient Ecosystems: Bridging Natural and Social Sciences" (TREBRIDGE) aims to identify policy and management approaches for alpine ecosystems to increase their resilience taking into account societal needs regarding natural resource use and protection. Similar to TRAPEGO, it pursues an ITD approach, which is seen as critical for project success since "the complex, crosscutting, and multi-faceted nature of ecosystems cannot be tackled adequately by a single discipline or disconnected approaches" (Lieberherr et al. 2021, p. 5).

The two projects are similar in many other respects, including their geographical focus, duration, and funding source (see Table 3). Both ITD projects have a separate work package dealing with science integration and aiming to bridge the various work packages within the projects. Furthermore, both projects aim for knowledge integration and solution development. To do so, they pursue disciplinary publications within separate work packages alongside integrated publications in inter- and transdisciplinary journals as well as in the form of policy briefs and other practice outputs. In addition, both projects organize, facilitate, and participate in a series of workshops to envision pathways to sustainability. This combination bridges the dichotomy between knowledge-first and process-oriented projects (Miller 2013). Almost all researchers in the two projects are affiliated with public universities or research institutes.[2] Both projects also involve societal stakeholders, for example, through an advisory board. These similarities

[2] An exception are two team members in TRAPEGO from an independent research institute. For more information on both projects, see www.trapego.ch/en and https://narp.ethz.ch/en/research/ongoing-projects/trebridge.html

**Table 2** Guiding questions for reflection

| Level | Question |
|---|---|
| Individual | 1. What opportunities do you experience with respect to your roles (e.g., in terms of synergies, resources, expectations)? |
| | 2. What challenges do you face with respect to your roles (e.g., in terms of tensions between specific roles, resources, expectations)? |
| | 3. What coping strategies have you developed to seize these opportunities or address these challenges? |
| Project | 4. To what extent does the combination of roles in your team fit the project goals? |
| | 5. What opportunities and challenges does the combination of roles in the project entail, and what coping strategies do you see? |

Compiled by the authors

allow for a meaningful comparison across the two ITD projects.

Differences between the projects can be found in the natural and social science disciplines involved and in the societal context of the issue investigated. Importantly, while both projects are clearly interdisciplinary, they differ in their degree of transdisciplinarity. Each project features an advisory board that, through annual meetings, has provided stakeholder feedback on the planned research activities and their political and/or practical relevance. In TRAPEGO, knowledge co-production with stakeholders has been used only in specific parts of the project. Based on their experience and expertise, stakeholders identified best practices of evidence use in pesticide governance, provided feedback on the design of survey questionnaires, and were crucial informants to assess the impacts of different policy and practice options in a multi-criteria decision analysis. By contrast, in TREBRIDGE, knowledge co-production has been an integral part of the overall project design, as a participatory scenario development process together with stakeholders is at the heart of the project. For example, stakeholders identified together with researchers key parameters for future scenarios (e.g., context factors, drivers of change) and co-developed four plausible scenarios for three case study regions. They will also assess policy and management options under different scenarios toward the end of the project. Overall, the moderate variance in project characteristics provides a basis for empirical insights that can inform hypothesis-building beyond a single project context.

The design and application of the reflection tool has been part of our accompanying research in these two ITD projects. The aim of this accompanying research has been to produce integrated knowledge about researchers' roles in both ITD projects, which Defila and Di Giulio (2018) describe as 'meta-type research'. This meta-type research has aimed for exploring and analyzing researchers' role(s) as well as for feeding the findings back to the project team to enable it to adapt processes, if necessary. In doing so, we have taken on a dual role of traditional scientists and process facilitators (Salomon 2023). As traditional scientists, we have designed and implemented the reflection tool to explore researchers' roles in both ITD projects. As process facilitators, we have enabled critical reflection on researchers' roles at individual and project level that have triggered some adaptations in both projects. This dual role has allowed us to conduct research on researchers' roles with in-depth knowledge of both projects and has provided a rich basis for interpretation of workshop results, including self-reflection and reflection of others on our own roles (cf. Hoffmann et al. 2017a; Verwoerd et al. 2020).

## Data collection and analysis

In both ITD projects, the application of the reflection tool focused on the researchers and made use of the same workshop setting for data gathering (see Supplementary Material). In a first step, we asked the researchers to fill out the role survey individually. The researchers then mapped their individual results on the spider web graph showing which roles each researcher takes up and to what degree. Additionally, we asked the researchers to individually reflect on opportunities and challenges they experience with respect to these roles (e.g., synergies, tensions, resources, expectations) and strategies they might have developed to seize opportunities and/or address challenges. In a second step, we asked the researchers to build breakout groups of five to six people, copy their individual results to a group spider web graph summarizing the combination of roles of that group, and share their results and insights within the groups. As the leaders of science integration in both projects, we moderated this exchange and noted down challenges and opportunities on a flipchart. In a third step, we summarized the breakout group results in the plenum and initiated a discussion about the fit of the combination of roles with the project goals in terms of contributions to academia and societal problem-solving (cf. Salomon 2023). In total, we gathered data from 29 researchers in the two projects (TRAPEGO: 16; TREBRIDGE: 13).[3]

[3] Data from researchers who could not attend the workshop was gathered electronically shortly after the workshop. In TRAPEGO, this was the case for four researchers, in TREBRIDGE for two. The paper authors themselves are part of the data: BH in TRAPEGO, HS in TREBRIDGE, and SH in both TRAPEGO and TREBRIDGE.

**Table 3** Comparison of ITD research projects in which tool was applied

| | TRAPEGO<br>Transformation in Pesticide Governance | TREBRIDGE<br>Transformation Toward Resilient Ecosystems |
|---|---|---|
| Empirical research focus | Agricultural pesticide use | Alpine watershed management |
| Geographic focus | Switzerland | Switzerland |
| Project duration | 2021–2025 | 2022–2026 |
| Budget | CHF 2.8 million | CHF 2.3 million |
| Funding source | Swiss National Science Foundation: Sinergia program | Swiss National Science Foundation: Sinergia program |
| Number of research institutes | 5 | 4 |
| Total number of researchers in project* | 17 | 15 |
| Thereof | | |
| Seniors (professors, group leaders) | 9 | 10 |
| Juniors (postdocs, PhDs, scientific assistants) | 8 | 5 |
| Thereof | | |
| Natural scientists (incl. public health researchers) | 8 | 8 |
| Social scientists | 9 | 7 |
| Disciplines or fields involved | Agronomy, agricultural economics, decision analysis, environmental sciences, political science, public health, and inter- and transdisciplinary studies | Environmental economics, forest ecology, geology, geomorphology, hydrology, natural resource policy, and inter- and transdisciplinary studies |
| Number of stakeholders in advisory board | 16 | 12 |
| Thereof | | |
| Public administration (national) | 4 | 3 |
| Public administration (subnational) | 2 | 6 |
| Private sector | 6 | 0 |
| Research and civil society | 4 | 3 |
| Knowledge co-production | In sub-parts of the project, e.g., collection of best practices of evidence, design of questions in farmer surveys, and assessment of pesticide policy options | Across entire project, including development of scenarios, prioritization thereof, and acceptance of policy and management options for the different scenarios |
| Knowledge integration | Integrated understanding of role of evidence for sustainable policy and practice, especially impact of evidence on attitudes of actors in Swiss agriculture towards pesticide use and regulation | Holistic understanding of the functioning of geomorphic processes in water and forest ecosystems; insights on plural valuation of nature (including non-monetary values) |
| Solution development | Policy and practice options for reducing environmental and human health risks of agricultural pesticides | Policy and management options for enabling transformation towards resilient water and forest ecosystems |
| Societal context of project | Conflictive: actor coalitions with competing policy preferences | Cooperative: 'coalitions of the willing' committed to project goals |

*At time of role workshop. Compiled by the authors

We documented the contents of the group and plenum discussions during the workshops as well as afterwards based on audio recordings and own memories.

We analyzed the data by identifying overarching themes across the two ITD projects and comparing them with each other. Due to differences in internal project timelines, we conducted the workshops at different points in time from the start of each project (TRAPEGO: 19 months; TREBRIDGE: 5 months). As we will discuss later, this imposes some limitations to our comparison but also suggests new hypotheses about changes in researchers' roles throughout a project. For each project, the theoretical perspectives reviewed above guided the analysis of the role profiles of the researchers, whereas the analysis of their reflection was inductive. After separate analysis for each project, we compared the results with a focus on identifying patterns that could inspire future research.

## Results

This section presents the ex-post analysis of empirical data collected with the role reflection tool from researchers working in the ITD projects TRAPEGO and TREBRIDGE. We compare their role profiles in three dimensions (aggregated role profiles of all researchers, seniority of researchers, and disciplinary affiliation) and summarize the reflection on opportunities, challenges, and coping strategies on individual and project level.

### Comparison of role profiles between projects

Our first comparison focuses on the aggregated role profiles of all researchers in each project. The role profiles of both projects share several similarities. To begin with, both projects show a broad diversity of roles on project level (see Fig. 1) as well as diverse role combinations on individual level. Among the six roles covered, the traditional scientists is most prominent in both projects. Many scientists are anchored in this role and, on top of it, take on additional roles. This pattern is reflected in the publication strategies of both projects, which mainly target disciplinary outlets complemented with integrated publications in inter- and transdisciplinary journals. The knowledge integrator role is relatively strong in both projects, too, while the change agent role was weakest. Underneath the similar breadth and diversity of roles in both projects, however, we found differences for certain roles. Knowledge broker and process facilitator roles were less strongly represented in TREBRIDGE than in TRAPEGO. Conversely, TREBRIDGE researchers self-identified more strongly with tasks of self-reflexive scientists.

Our second comparison concerns the role profiles of senior and junior researchers. Senior researchers include professors and group leaders, whereas junior researchers include postdocs, PhDs, and scientific assistants. In both projects, senior researchers performed a higher number of change agent tasks, whereas junior researchers saw themselves more strongly as self-reflexive scientists (see Fig. 2). By contrast, senior and junior researchers had comparable levels of engagement in the roles of traditional scientist and process facilitator. The same applies to

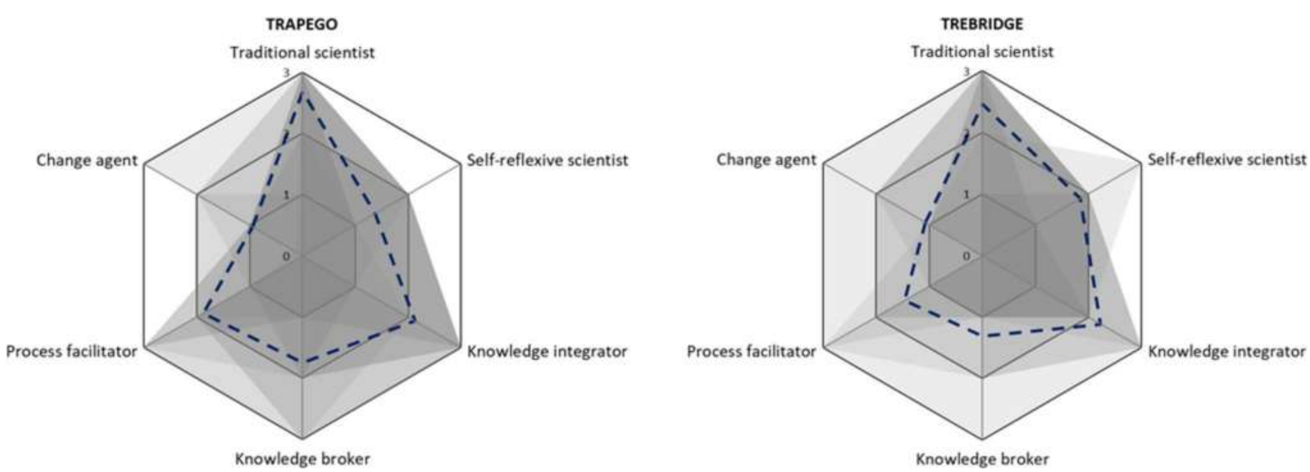


**Fig. 1** Comparison of role profiles of researchers on project level. The spider webs map the number of tasks taken on by researchers per role. The dotted blue line shows the average number of tasks per role across all researchers. The grey areas show the overlaid role profiles of individual researchers, with darker areas indicating overlap of many researchers and lighter areas indicating less overlap. White areas mean that none of the role profiles covers this role or role combination. Compiled by the authors, for TREBRIDGE: Salomon (2023)

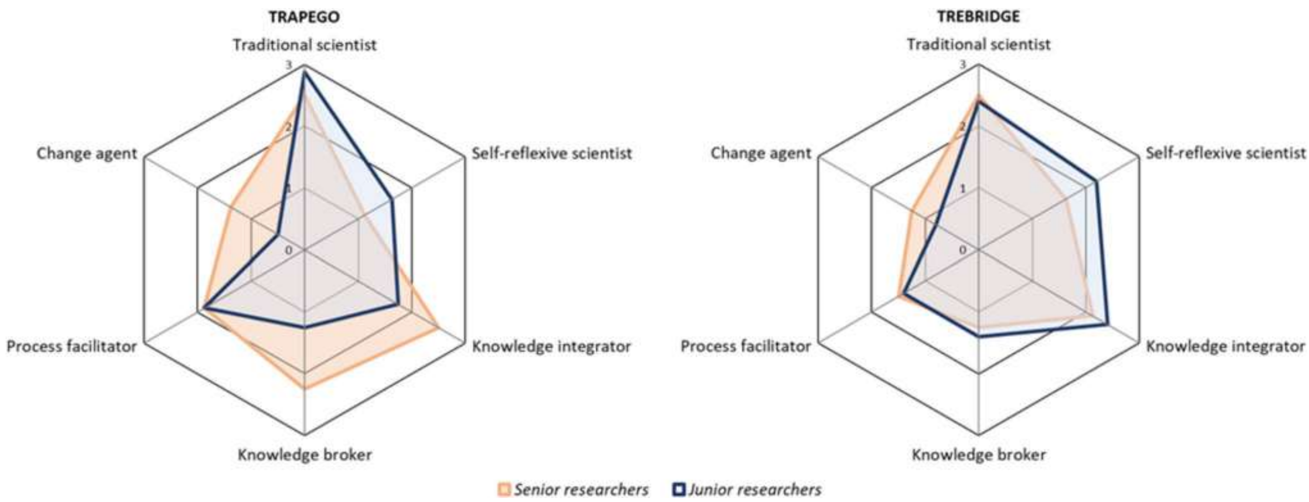


**Fig. 2** Comparison of role profiles of senior and junior researchers. The spider web maps the average number of tasks taken on by all senior researchers (= orange line) and all junior researchers (= blue line) per role. Compiled by the authors

knowledge integrator and knowledge broker roles in TREBRIDGE, whereas in TRAPEGO senior researchers engaged more strongly in these roles. The two project leaders, who are part of the senior researcher group, had a very broad role profile. Thus, seniority seems to influence which roles researchers assume, especially in terms of self-reflexivity and pushing for societal change.

Our third comparison is the distinction between natural and social scientists according to researchers' current department and disciplinary affiliation. In both projects, it was mostly social scientists who performed the three roles of knowledge integrator, knowledge broker, and process facilitator (see Fig. 3). The differences were less clear-cut for the other three roles. Natural scientists (including health scientists) and social scientists took on a comparable level of traditional scientist tasks in TRAPEGO, whereas natural scientists scored higher on this role in TREBRIDGE. For self-reflexive scientist tasks, natural and social scientist were roughly on equal level in both projects. For the change agent role, natural scientists clearly dominated this role in TRAPEGO, whereas in TREBRIDGE natural and social science researchers were on similar levels again. Hence, disciplinary patterns across projects are observed for roles related to integration, brokerage, and facilitation—but not for others.

In summary, researchers assumed a broad diversity of roles in the two ITD projects. Project context as well as distinctions between senior and junior researchers and between

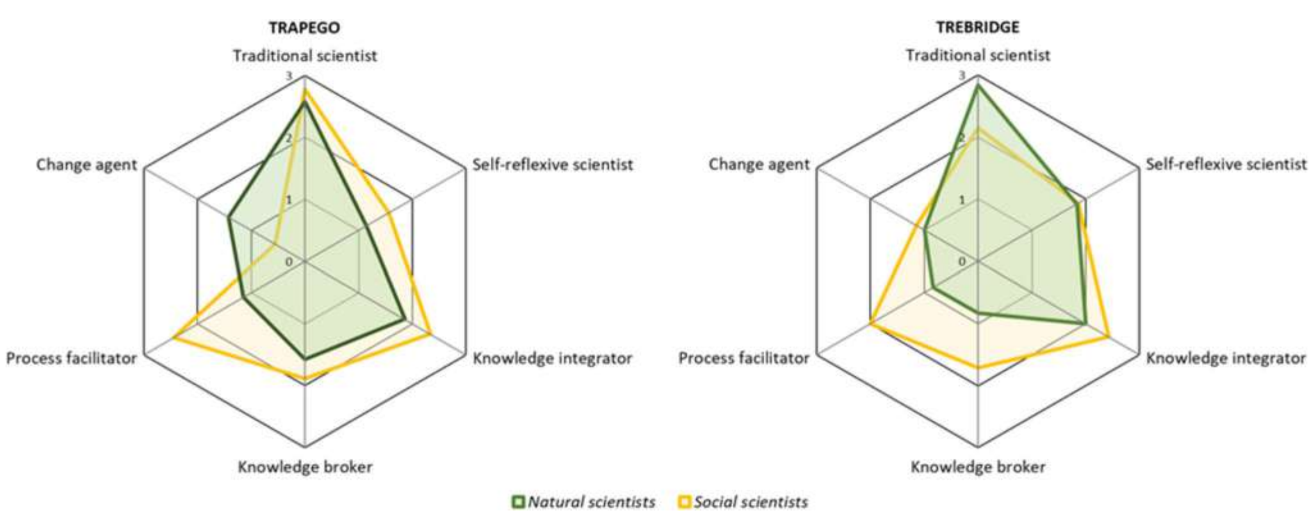


**Fig. 3** Comparison of role profiles of natural and social scientists. The spider web maps the average number of tasks taken on by all natural scientists (= green line) and all social scientists (= yellow line) per role. For TRAPEGO, natural scientists include public health researchers. Compiled by the authors

natural and social scientists seem to matter for understanding which roles researchers take on.

### Opportunities and challenges of role profiles

The tool allowed for individual and collective reflection on researchers' own roles and roles of others as well as on the combination of role profiles at project level. A few differences in terms of role perceptions were detected. Some researchers did not think they performed many change agent tasks, whereas their colleagues thought they did, sparking discussion on the extent to which researchers do and should play this role in both ITD projects. Furthermore, the role workshop provided time and space to explore and reflect on the opportunities and challenges that arise when assuming different roles in ITD projects. It also allowed for joint discussion of coping strategies to overcome challenges and leverage opportunities (see Table 4).

In both ITD projects, researchers mentioned two general opportunities related to the project-level role profiles (for TREBRIDGE, cf. Salomon 2023). One opportunity is to have researchers spread across roles within the project team. On individual level, this offers possibilities for exploring different roles within the ITD project and for learning from others, which helps improve own research and its impact. On project level, researchers with different roles can complement each other, supporting division of labor and more focused individual role profiles. Another opportunity is to have a separate work package within the ITD project to ensure reflection on individual and collective role profiles. For instance, making existing role combinations transparent facilitated discussions about spill-overs and (in-)compatibilities between roles. Role diversity is an opportunity provided that researchers are aware of it and actively reflect on it.

A general challenge identified by several researchers was the difficulty of maintaining high engagement in multiple roles in light of time, capacity, and resource constraints. This is most pronounced when own role expectations and project requirements partly diverge. As a coping strategy, participants identified ongoing individual and collective reflection on role profiles (e.g., on whether one has to take on all indicated roles) as well as pragmatism (e.g., consider feasibility and prioritize certain roles). For instance, joint exploration of role profiles in project workshops could be a basis for taking decisions on role distribution within the project team and corresponding resource allocation and capacity-building. In both projects, following application of the reflection tool, researchers with very broad role profiles started to delegate more tasks instead of trying to cover all roles to a high extent themselves. Coping strategies were also devised in relation to specific roles. For instance, self-reflexive scientists indicated the need for more time to step back and reflect on the research process and related power dynamics. Regular meetings and exchange among junior researchers in both projects served as such a reflection space. For us co-authors, who have combined knowledge integrator, knowledge broker, and process facilitator roles, another challenge is that collaborative processes usually take long. The time needed for preparing inter- and transdisciplinary publications clashes with the "publish or perish" imperative that still determines academic career prospects (Purvis et al. 2023). This challenge could best be addressed through changing incentive and reward structures within academia, illustrating the limitations of developing coping strategies on project level (Deutsch et al. 2025b).

## Discussion

The diverse role profiles we mapped reflect the combination of knowledge integration, knowledge co-production, and solution development in both ITD projects, bridging the divide between knowledge-first and process-oriented goals. The results confirm the persistent strength of the traditional scientist role even in ITD research, as research remains anchored in disciplines with ITD research being an add-on (Deutsch et al. 2025b). At the same time, strong presence of the knowledge integrator role in both projects reflects the ITD priority of the funding scheme and the dedicated planning of science integration by senior researchers (Lieberherr et al. 2021; Ingold et al. 2024). According to the discussion in both projects, the weak position of the change agent role may be due to the newness of the role (Hilger et al. 2021), uncertainty on the part of researchers about the role's legitimacy, perceived reputation risks, and potentially also their affiliation with public research organizations. The reflection about being a change agent suggests that stakes of policy and practice actors influence the roles adopted by them. The conflictive setting of Swiss pesticide policy, with competing coalitions that support or oppose stringent measures, made researchers in TRAPEGO hesitant to embrace this role—a problem not observed in TREBRIDGE, embedded in a more cooperative setting of Swiss water and forest management. Additionally, researchers in both projects emphasized the importance of the time dimension, as role profiles might change. The reflection also raised questions about distributing roles within project teams in a way that ensures division of labor, which deviates from the idea that other roles come on top of the traditional scientist. Such division of labor may reduce tensions experienced by individual researchers, especially project leaders, when taking on many different roles within a project but may create new challenges in ensuring interconnectedness of different roles.

Our results revealed interesting preliminary patterns in role distribution within the ITD project teams. Senior researchers assuming a stronger change agent role may

**Table 4** Opportunities, challenges, and coping strategies mentioned during the application of the tool

| | Opportunities | Challenges | Coping strategies | Literature related to challenges |
|---|---|---|---|---|
| *Individual roles* | | | | |
| Traditional scientist | Deepen one's specific knowledge in one discipline or field | Get access to field (e.g., for data collection) without strong prior relationships with stakeholders | Set up advisory board with stakeholders to facilitate data access | Robson and McCartan (2016) |
| Self-reflexive scientist | See the bigger picture and reflect on how and why one does own research | Reserve time to step back and reflect on own research | Build in time at project level for regular reflection from the beginning of the project to the end | Verwoerd et al. (2020) |
| Knowledge integrator | Learn how to translate own findings into other (inter-)disciplinary languages and connect to other disciplines and fields | Gain recognition for own intellectual contributions | Make own contributions explicit | Ding et al. (2020) and Hoffmann et al. (2022) |
| Knowledge broker | Open up to different views and ways of thinking (e.g., learning new vocabularies when translating own findings for stakeholders) | Overcome (trans-)disciplinary language barriers when communicating with stakeholders | Learn from fellow researchers and own experience | Nurius and Kemp (2019) |
| Process facilitator | Enhance competencies that can be employed in different contexts later on | Open up discussions within the whole project team while ensuring autonomy of decision-making within sub-groups | Create moments of self-reflection and joint group reflection to facilitate learning | Bell and Morse (2013) |
| Change agent | Create possibility for actionable real-life change | Navigate demanding and exhausting power plays | Distribute roles within project team and create institutional support structures (e.g., advisory board with stakeholders) | Wittmayer and Schäpke (2014) |
| *Combination of roles* | | | | |
| Knowledge integrator, knowledge broker, and process facilitator | Positive spill-overs between roles, e.g., interactions with researchers and stakeholders in facilitator role support integrator and broker roles | Keep overview of the project's research and the empirical data gathered by 'traditional scientists', and time needed for integration | Attend regular meetings and exchange with 'traditional scientists' to keep abreast of project developments | Deutsch et al. (2025a) |
| Traditional scientist and change agent | Good opportunity to also be a change maker rather than adhering solely to the role of traditional scientist | Run the risk of undermining one's own legitimacy and reputation as scientist | Make assumptions about role of science in relation to policy and practice explicit as well as ground work in solid science records and methods | Bulten et al. (2021) |

Compiled by the authors

indicate that they possess larger and more sustained stakeholder networks and/or that their more secure academic position allows them to take more time and risks in engaging with policy and practice (Sobey et al. 2013; cf. Evans and Cvitanovic 2018; Guimarães et al. 2019). In turn, stronger self-reflectiveness of junior researchers may show that, as they have not been fully socialized into one discipline or way of doing research yet or are distinctively cross- or undisciplinary (Knaggård et al. 2018; Haider et al. 2018), they still ask more critical questions about why and how to do their own research than senior researchers. Furthermore, the strong reliance on social scientists for taking the roles of knowledge integrator, knowledge broker, and process facilitator may be associated with the skills they bring to the project. All three roles require engagement with social processes that social scientists may have studied as part of their education and training (Ding et al. 2020, p. 7). However, this pattern may change when more dedicated ITD education and training of integration, brokerage, and facilitator skills is offered across different study programs, including the natural sciences (Haider et al. 2018; cf. Horn et al. 2023). The diverse role profiles we mapped underscore the need for a more flexible publication culture and for institutional structures (e.g., incentives, and rewards) that support dynamic and adaptive careers (Miller et al. 2011).

Regarding our goal of enabling researchers to make practical use of the literature on roles in ITD research, the empirical application confirms the value of the proposed reflection tool. First, the tool allowed for detecting a diversity of roles that individual researchers assume, thus providing a richer picture than typologies with mutually exclusive roles. Second, its focus on six roles proved to be a parsimonious design that supported efficient application and balanced role diversity and overlaps. Third, the transparent and multi-dimensional reflection sparked by the tool supports improved collaboration in ITD projects, for instance, by facilitating more conscious decisions about roles. Despite these contributions, we see potential for further developing the tool in different application contexts. To begin with, the set of reflection questions can be expanded depending on the goals of its use in ITD projects (e.g., to enhance role clarity, discuss division of labor, or identify gaps in a project team). Furthermore, making the reflection tool easily accessible and usable to everyone (e.g., in an online version) would allow for gathering, sharing, and comparing data on researchers' roles across a larger sample, which is imperative to draw more representative conclusions on role patterns. More fundamentally, critical transition and action researchers may want to reframe the role descriptions towards "counter-hegemonic knowledge production" that criticizes "normal" knowledge and experiments with alternative knowledge (Jhagroe 2018, p. 66). Beyond this, we have gathered more specific suggestions for further development, especially of the role survey (see Supplementary Material).

Five major limitations apply to our analysis. First, the designation of natural vs. social scientists was based on current department and disciplinary affiliation, but paints over diverse biographies that, for several people, involve both natural and social science disciplines. To unpack this dimension, future research could investigate links between the biographies and careers of researchers and their roles in ITD projects. Second, the two ITD projects we compared may not be representative for all ITD projects as they were funded by the same funding scheme and have similar science integration designs. Gathering more data about researchers' roles in ITD projects from other funding contexts and project set-ups may help to substantiate the preliminary patterns we identified. Third, we applied the reflection tool only once in each project. It would be interesting to monitor the change in role profiles in different project phases with varying stakeholder involvement (Stauffacher et al. 2008). Fourth, most researchers in the projects analyzed are affiliated with public research organizations. Role profiles of researchers from other types of organizations, such as independent or private institutes, might look different. Fifth, we focused on interdisciplinary project teams of academic researchers and did not elicit stakeholders' roles or their perceptions of the roles played by researchers. Gathering such data may be useful for external validation of role profiles.

## Conclusion

The paper set out to explore what is needed to support researchers in making use of the growing literature on the roles they can and do play in ITD projects. We developed and empirically applied a new reflection tool for six key roles of researchers in ITD projects aimed at knowledge co-production, knowledge integration, and solution development. We described its application in two ITD projects in the field of sustainable transformation. We observed that the tool (1) made individual researchers aware of the diverse roles they play; (2) made researchers identify opportunities, challenges, and coping strategies related to this role diversity; (3) revealed differences in their own and others' perceptions of researchers' roles within both project teams; (4) depicted the combination of researchers' roles on project level; and, thereby, (5) sparked project-level discussions about how well this collective role profile aligns with project goals. We conclude that the tool is useful for enhancing reflection on researchers' roles in ITD projects, noting some aspects for consideration in future application and refinement (see Supplementary Material).

Our contribution can inspire future research into different aspects of roles in ITD research. One aspect is to assess the success of the coping strategies taken up after the reflection workshop as well as their link to more structural changes within academia beyond individual projects (Deutsch et al. 2025b). Moreover, it would be valuable to investigate how the distribution of roles within ITD projects shapes their outputs, notably whether the role diversity we mapped with the reflection tool enhances the ability of researchers to produce robust, salient, and credible knowledge in the eyes of stakeholders (Cash et al. 2003). In transdisciplinary research contexts, the reflection tool could be used to examine how stakeholders view researchers' role profiles and thus prevent potential misunderstandings due to differences in role perceptions. Another aspect is to see whether reflection in different contexts (e.g., ITD projects with researchers from independent or private institutes) would reveal higher values for action-oriented roles, such as change agent or knowledge broker. Likewise, it might be useful to plan the reflection on roles at the outset of the project to allow for tracing changes over time (cf. Salomon 2023). Researchers could also use ex-ante reflection to indicate which tasks they anticipate to perform in the project and later assess whether they have taken on the anticipated roles. The reflection tool could even be used during the recruitment process of an ITD team to make the role expectations of the project lead and of the candidate transparent. Finally, future research could study career prospects of different roles, especially of undisciplined combinations of knowledge- and process-oriented tasks that may lead researchers into "uncomfortable borderlands between the academy and the larger world" (Robinson 2008, p. 72; cf. Guimarães et al. 2019).

The reflection on roles we proposed is broad and flexible enough to cover and be customized to many different ITD research contexts. On project level, application of the reflection tool to other ITD projects would create comparable data and allow for systematic empirical investigation of researchers' roles, including the preliminary role patterns we detected with regard to senior and junior researchers as well as natural and social scientists. Additionally, it can complement existing tools aimed at clarifying stakeholder roles in ITD research (e.g., Pohl et al. 2017). At individual level, application of the tool might foster researchers' awareness of their own roles in different ITD projects and how their roles align. Such increased awareness and clarity of roles is a precondition for harnessing the opportunities and addressing the challenges that many researchers experience in ITD projects aimed at knowledge co-production, knowledge integration, and solution development.

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**Author contributions** BH and HS share first co-authorship. BH and SH developed the reflection tool and applied it in TRAPEGO; HS and SH applied the tool in TREBRIDGE. BH and HS led the paper writing and revision process. All authors contributed equally to improving the ideas and the text.

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**Data availability** The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request. Data are located in controlled access data storage at Eawag.

## Declarations

**Conflict of interest** The authors have no conflict of interest to declare that might have influenced the content of this article.

**Informed consent** All study participants consented to the use of their anonymized data for the purpose of the research explained to them and approved the manuscript before submission.



## References

Adelle C, Pereira L, Görgens T, Losch B (2020) Making sense together: the role of scientists in the coproduction of knowledge for policy making. Sci Public Policy 47:56–66. https://doi.org/10.1093/scipol/scz046

Arnold MG (2022) The challenging role of researchers coping with tensions, dilemmas and paradoxes in transdisciplinary settings. Sustain Dev 30:326–342. https://doi.org/10.1002/sd.2277

Avelino F, Grin J (2017) Beyond deconstruction. a reconstructive perspective on sustainability transition governance. Environ Innov Soc Trans 22:15–25. https://doi.org/10.1016/j.eist.2016.07.003

Bell S, Morse S (2013) Groups and facilitators within problem structuring processes. J Oper Res Soc 64:959–972. https://doi.org/10.1057/jors.2012.110

Bulten E, Hessels LK, Hordijk M, Segrave AJ (2021) Conflicting roles of researchers in sustainability transitions: balancing action and reflection. Sustain Sci 16:1269–1283. https://doi.org/10.1007/s11625-021-00938-7

Caniglia G, Luederitz C, von Wirth T et al (2021) A pluralistic and integrated approach to action-oriented knowledge for sustainability. Nat Sustain 4:93–100. https://doi.org/10.1038/s41893-020-00616-z

Cash DW, Clark WC, Alcock F et al (2003) Knowledge systems for sustainable development. Proc Natl Acad Sci 100:8086–8091. https://doi.org/10.1073/pnas.1231332100

Crouzat E, Arpin I, Brunet L et al (2018) Researchers must be aware of their roles at the interface of ecosystem services science and policy. Ambio 47:97–105. https://doi.org/10.1007/s13280-017-0939-1

Defila R, Di Giulio A (2018) What is it good for? Reflecting and systematizing accompanying research to research programs. GAIA Ecol Perspect Sci Soc 27:97–104. https://doi.org/10.14512/gaia.27.S1.17

Deutsch L, Björnsen A, Fischer AM et al (2025a) Herding cats: integrative leadership strategies in inter- and transdisciplinary research programs. Sustain Sci. https://doi.org/10.1007/s11625-024-01585-4

Deutsch L, Pohl C, Bresch D, Hoffmann S (2025b) Creating favorable conditions for inter- and transdisciplinary integration—an analytical framework and empirical insights. Glob Environ Change 91:102963. https://doi.org/10.1016/j.gloenvcha.2024.102963

Ding Y, Pulford J, Bates I (2020) Practical actions for fostering cross-disciplinary global health research: lessons from a narrative literature review. BMJ Glob Health 5:e002293. https://doi.org/10.1136/bmjgh-2020-002293

Donner S (2014) Finding your place on the science - advocacy continuum: an editorial essay. Clim Change 124:1–8. https://doi.org/10.1007/s10584-014-1108-1

Evans MC, Cvitanovic C (2018) An introduction to achieving policy impact for early career researchers. Palgrave Commun 4:1–12. https://doi.org/10.1057/s41599-018-0144-2

Fazey I, Schäpke N, Caniglia G et al (2018) Ten essentials for action-oriented and second order energy transitions, transformations and climate change research. Energy Res Soc Sci 40:54–70. https://doi.org/10.1016/j.erss.2017.11.026

Felt U (2022) Making and taking time: Work, funding and assessment infrastructures in inter- and trans-disciplinary research. In: Vienni-Baptista B, Klein JT (eds) Institutionalizing interdisciplinarity and transdisciplinarity collaboration across cultures and communities. Routledge, London, pp 204–217

Glänzel W, Debackere K (2022) Various aspects of interdisciplinarity in research and how to quantify and measure those. Scientometrics 127:5551–5569. https://doi.org/10.1007/s11192-021-04133-4

Guimarães MH, Pohl C, Bina O, Varanda M (2019) Who is doing inter- and transdisciplinary research, and why? An empirical study of motivations, attitudes, skills, and behaviours. Futures 112:102441. https://doi.org/10.1016/j.futures.2019.102441

Haider LJ, Hentati-Sundberg J, Giusti M et al (2018) The undisciplinary journey: early-career perspectives in sustainability science. Sustain Sci 13:191–204. https://doi.org/10.1007/s11625-017-0445-1

Hazard L, Cerf M, Lamine C et al (2020) A tool for reflecting on research stances to support sustainability transitions. Nat Sustain 3:89–95. https://doi.org/10.1038/s41893-019-0440-x

Hilger A, Rose M, Wanner M (2018) Changing faces—factors influencing the roles of researchers in real-world laboratories. GAIA Ecol Perspect Sci Soc 27:138–145

Hilger A, Rose M, Keil A (2021) Beyond practitioner and researcher: 15 roles adopted by actors in transdisciplinary and transformative research processes. Sustain Sci 16:2049–2068. https://doi.org/10.1007/s11625-021-01028-4

Hoffmann S, Pohl C, Hering JG (2017a) Methods and procedures of transdisciplinary knowledge integration: empirical insights from four thematic synthesis processes. Ecol Soc 22:27. https://doi.org/10.5751/ES-08955-220127

Hoffmann S, Pohl C, Hering JG (2017b) Exploring transdisciplinary integration within a large research program: empirical lessons from four thematic synthesis processes. Res Policy 46:678–692. https://doi.org/10.1016/j.respol.2017.01.004

Hoffmann S, Deutsch L, Klein JT, O'Rourke M (2022) Integrate the integrators! A call for establishing academic careers for integration experts. Humanit Soc Sci Commun 9:147. https://doi.org/10.1057/s41599-022-01138-z

Hofmann B, Ingold K, Stamm C et al (2023) Barriers to evidence use for sustainability: insights from pesticide policy and practice. Ambio 52:425–439. https://doi.org/10.1007/s13280-022-01790-4

Hoffmann S, Deutsch L, O'Rourke M (2024) Integration experts and expertise. In: Darbellay F (ed) Elgar encyclopedia of inter- and transdisciplinarity. Edward Elgar Publishing, Cheltenham, pp 273–276

Horlings LG, Nieto-Romero M, Pisters S, Soini K (2020) Operationalising transformative sustainability science through place-based research: the role of researchers. Sustain Sci 15:467–484. https://doi.org/10.1007/s11625-019-00757-x

Horn A, Urias E, Klein JT et al (2023) Expert and non-expert at the same time: knowledge integration processes and dynamics in interdisciplinary teamwork. Sustain Sci 18:2357–2371. https://doi.org/10.1007/s11625-023-01365-6

Huning S, Räuchle C, Fuchs M (2021) Designing real-world laboratories for sustainable urban transformation: addressing ambiguous roles and expectations in transdisciplinary teams. Sustain Sci 16:1595–1607. https://doi.org/10.1007/s11625-021-00985-0

Ingold K, Eggen R, Finger R, Probst-Hensch N (2024) Evidence-based transformation in pesticide governance. Scientific Abstract of SNSF Sinergia Project. In: Swiss National Science Foundation Data Portal. https://data.snf.ch/grants/grant/193762

Jhagroe S (2018) Transition scientivism: on activist gardening and co-producing transition knowledge 'from below.' In: Bartels KPR, Wittmayer JM (eds) Action research in policy analysis. Routledge, London, pp 64–85

Juhola S, Huotari E, Kolehmainen L et al (2024) Knowledge brokering at the environmental science-policy interface—examining structure and activity. Environ Sci Policy 153:103672. https://doi.org/10.1016/j.envsci.2024.103672

Kivimaa P, Boon W, Hyysalo S, Klerkx L (2019) Towards a typology of intermediaries in sustainability transitions: a systematic review and a research agenda. Res Policy 48:1062–1075. https://doi.org/10.1016/j.respol.2018.10.006

Knaggård Å, Ness B, Harnesk D (2018) Finding an academic space: reflexivity among sustainability researchers. Ecol Soc 23:20. https://doi.org/10.5751/ES-10505-230420

Kruijf JV, Verbrugge L, Schröter B et al (2022) Knowledge co-production and researcher roles in transdisciplinary environmental management projects. Sustain Dev 30:393–405. https://doi.org/10.1002/sd.2281

Lang DJ, Wiek A (2022) Structuring and advancing solution-oriented research for sustainability. Ambio 51:31–35. https://doi.org/10.1007/s13280-021-01537-7

Lang DJ, Wiek A, Bergmann M et al (2012) Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain Sci 7:25–43. https://doi.org/10.1007/s11625-011-0149-x

Laursen B, Vienni-Baptista B, Bammer G et al (2024) Toolkitting: an unrecognized form of expertise for overcoming fragmentation in inter- and transdisciplinarity. Humanit Soc Sci Commun 11:1–10. https://doi.org/10.1057/s41599-024-03279-9

Lieberherr E, Bugmann H, Hoffmann S, Schlunegger F (2021) Transformation toward resilient ecosystems: bridging natural and social sciences (TREBRIDGE). Proposal for SNSF Sinergia Project

McGowan K, Westley F, Fraser E et al (2014) The research journey: travels across the idiomatic and axiomatic toward a better understanding of complexity. Ecol Soc 19:37. https://doi.org/10.5751/ES-06518-190337

Miller TR (2013) Constructing sustainability science: emerging perspectives and research trajectories. Sustain Sci 8:279–293. https://doi.org/10.1007/s11625-012-0180-6

Miller T, Muñoz-Erickson T, Redman C (2011) Transforming knowledge for sustainability: towards adaptive academic institutions. Int J Sustain High Educ 12:177–192. https://doi.org/10.1108/14676371111118228

Miller TR, Wiek A, Sarewitz D et al (2014) The future of sustainability science: a solutions-oriented research agenda. Sustain Sci 9:239–246. https://doi.org/10.1007/s11625-013-0224-6

Norström AV, Cvitanovic C, Löf MF et al (2020) Principles for knowledge co-production in sustainability research. Nat Sustain 3:182–190. https://doi.org/10.1038/s41893-019-0448-2

Nurius PS, Kemp SP (2019) Individual-level competencies for team collaboration with cross-disciplinary researchers and stakeholders. In: Hall KL, Vogel AL, Croyle RT (eds) Strategies for team science success: handbook of evidence-based principles for cross-disciplinary science and practical lessons learned from health researchers. Springer, Cham, pp 171–187

O'Rourke M, Crowley S, Gonnerman C (2016) On the nature of cross-disciplinary integration: a philosophical framework. Stud Hist Philos Sci Part C Stud Hist Philos Biol Biomed Sci 56:62–70. https://doi.org/10.1016/j.shpsc.2015.10.003

Peltola T, Saarela S-R, Kotilainen JM et al (2023) Researcher roles in collaborative governance interventions. Sci Public Policy 50:871–880. https://doi.org/10.1093/scipol/scad034

Pielke RA Jr (2007) The honest broker: making sense of science in policy and politics. Cambridge University Press, Cambridge

Pohl C, Rist S, Zimmermann A et al (2010) Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Sci Public Policy 37:267–281. https://doi.org/10.3152/030234210X496628

Pohl C, Krütli P, Stauffacher M (2017) Ten reflective steps for rendering research societally relevant. GAIA Ecol Perspect Sci Soc 26:43–51

Pohl C, Klein JT, Hoffmann S et al (2021) Conceptualising transdisciplinary integration as a multidimensional interactive process. Environ Sci Policy 118:18–26. https://doi.org/10.1016/j.envsci.2020.12.005

Popa F, Guillermin M, Dedeurwaerdere T (2015) A pragmatist approach to transdisciplinarity in sustainability research: from complex systems theory to reflexive science. Futures 65:45–56. https://doi.org/10.1016/j.futures.2014.02.002

Purvis B, Keding H, Lewis A, Northall P (2023) Critical reflections of postgraduate researchers on a collaborative interdisciplinary research project. Humanit Soc Sci Commun 10:1–13. https://doi.org/10.1057/s41599-022-01494-w

Robinson J (2008) Being undisciplined: Transgressions and intersections in academia and beyond. Futures 40:70–86. https://doi.org/10.1016/j.futures.2007.06.007

Robson C, McCartan K (2016) Real world research, 4th edn. Wiley, Hoboken

Roux DJ, Nel JL, Cundill G et al (2017) Transdisciplinary research for systemic change: who to learn with, what to learn about and how to learn. Sustain Sci 12:711–726. https://doi.org/10.1007/s11625-017-0446-0

Salomon H (2023) Toward Resilient Ecosystems: An Analysis of the Opportunities and Challenges of Science Integration and Researcher's Roles. Master's thesis, ETH Zürich

Sarkki S, Heikkinen HI, Komu T et al (2020) How boundary objects help to perform roles of science arbiter, honest broker, and issue advocate. Science Public Policy 47:161–171. https://doi.org/10.1093/scipol/scz055

Schoolman ED, Guest JS, Bush KF, Bell AR (2012) How interdisciplinary is sustainability research? Analyzing the structure of an emerging scientific field. Sustain Sci 7:67–80. https://doi.org/10.1007/s11625-011-0139-z

Schrage J, Barraclough AD, Wilkerson B et al (2023) Developing positional awareness in sustainability science: four archetypes for early career scientists working in an SDG world. Sustain Sci 18:1053–1058. https://doi.org/10.1007/s11625-022-01239-3

Sobey AJ, Townsend NC, Metcalf CD et al (2013) Incorporation of early career researchers within multidisciplinary research at academic institutions. Res Eval 22:169–178. https://doi.org/10.1093/reseval/rvt004

Stauffacher M, Flüeler T, Krütli P, Scholz RW (2008) Analytic and dynamic approach to collaboration: a transdisciplinary case study on sustainable landscape development in a swiss prealpine region. Syst Pract Action Res 21:409–422. https://doi.org/10.1007/s11213-008-9107-7

Temper L, McGarry D, Weber L (2019) From academic to political rigour: Insights from the 'Tarot' of transgressive research. Ecol Econ 164:106379. https://doi.org/10.1016/j.ecolecon.2019.106379

Thompson GN, Estabrooks CA, Degner LF (2006) Clarifying the concepts in knowledge transfer: a literature review. J Adv Nurs 53:691–701. https://doi.org/10.1111/j.1365-2648.2006.03775.x

Turnhout E, Stuiver M, Klostermann J et al (2013) New roles of science in society: different repertoires of knowledge brokering. Sci Public Policy 40:354–365. https://doi.org/10.1093/scipol/scs114

Verwoerd L, Klaassen P, van Veen SC et al (2020) Combining the roles of evaluator and facilitator: assessing societal impacts of transdisciplinary research while building capacities to improve its quality. Environ Sci Policy 103:32–40. https://doi.org/10.1016/j.envsci.2019.10.011

Wittmayer JM, Schäpke N (2014) Action, research and participation: roles of researchers in sustainability transitions. Sustain Sci 9:483–496. https://doi.org/10.1007/s11625-014-0258-4

Wittmayer JM, Avelino F, van Steenbergen F, Loorbach D (2017) Actor roles in transition: insights from sociological perspectives. Environ Innov Soc Trans 24:45–56. https://doi.org/10.1016/j.eist.2016.10.003

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# Policies and patterns of integration of science and religion in Indonesian Islamic higher education

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**Abstract**
The integration of science and religion in the contemporary Islamic world has been debated. This article examines the policies and patterns of integration of science and religion in Islamic higher education institutions in Indonesia, focusing on Syarif Hidayatullah State Islamic University (UIN/Universitas Islam Negeri) Jakarta. This research is a field study whose primary sources are obtained through document data and interviews. The results show that, first, the integration policy officially rejects the Islamization of science but combines religious and general sciences or vice versa. This integration is patterned by identifying core and auxiliary sciences, and if the core science is religious, then the auxiliary science is general science and vice versa. Second, integration is seen from the work of lecturers, which is formulated into five forms, as follows: first, integration of scientific themes that are related; second, integration of references; third, integration of all sciences; fourth, integration of philosophical foundations (epistemological, ontological, and axiological); and fifth, integration of Islamic science with social science and cultural science approaches. This research concludes that the integration pattern at UIN Syarif Hidayatullah Jakarta is open, which allows it to continue to grow. This pattern can be referred to as open integration.

**Keywords** Integration of knowledge · Integration of science and religion · Integration model · Scientific work · Science integration policy · UIN Jakarta · A state Islamic university · Indonesia

## Introduction

Religious and intellectual leaders have long discussed the integration of knowledge at the national and global levels (Akbar, 2019; Çoruh, 2020; Hossein Khani, 2020). Globally, the Islamization of science is an attempt to integrate science with Islam, as Ismail al-Faruqi and Naquib al-Attas stated (Al-Attas, 1985; Al-Faruqi, 1987). Seyyed Hossein Nasr also has the concept of Islamization of knowledge, even though it is criticized as very utopian (Bukhari, 2019). In Indonesia, science integration is also discussed massively, especially after the transformation of Indonesian Islamic higher education institutions from State

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Islamic Institutes (Institut Agama Islam Negeri/IAIN) to State Islamic Universities (Universitas Islam Negeri/UIN). However, it does not use the framework of Islamization of science.

Among the prominent figures who developed the concept of integration include Amin Abdullah, whose concept of integration and interconnection is symbolized by a spider's web. He also published his new book on multidisciplinary, interdisciplinary, transdisciplinary religious, and Islamic studies (Abdullah, 2020). This concept later became the basis for the development of integration at UIN Sunan Kalijaga Yogyakarta. This is different from Imam Suprayogo, a figure from UIN Malang who initiated integration with the concept of the tree of knowledge, and this concept is the guideline for UIN Maliki Malang. UIN Surabaya developed the concept of integration with the Twins Tower symbol (Zainiyati, 2016). UIN Jakarta developed the concept of integration of knowledge without using symbols (metaphors). Azyumardi Azra tried to term this approach by reintegrating knowledge (Azra, 2000, 2013a).

In addition to discussing the concept of integration, leaders from *pesantren* (Islamic boarding schools) also participated in formulating the concept of integration. KH. Sahal Mahfudh is one of the *pesantren* leaders with the concept of integration with scientific synergy. Specifically, scientific synergy integrates the yellow book *(kitab kuning)* with various references and various other disciplines (Mahfudh, 1999, pp. 101–108). The integration of the *pesantren* tradition with the modern tradition is desired from the scientific synergy method so that the contextualization of the yellow book occurs. The concept of integration within Islamic educational institutions can then be said to be a characteristic of open Islamic education (Irham, 2022). The idea of integrating science and religion in Indonesia has even been discussed since President Sukarno. According to him, religious knowledge and general science should not have a dichotomy (Kurniawan, 2018).

In the context of Islamic higher education, the relationship between religion and science in that academic orientation is still an unfinished issue. If you look at contemporary developments, the scientific orientation of Islamic campuses worldwide is very diverse. There is an Islamic campus whose orientation is ideological and instills a certain religious sect, such as al-Mustafa International University (Banikamal & Ra'ees, 2018; Zulkifli, 2015), including those in Arabia, such as the Islamic University of Medina (Farquhar, 2015). There are also Islamic campuses that are considered failed and difficult to revitalize, and unproductive such as Niger Islamic University Lahore Pakistan (Haron, 2016). In Palestine, Islamic campuses provide education on Islamic values and Palestinian traditions, risks/dangers of war and awareness/emergency management (R. Abunamous, 2020; R. E. S. Abunamous et al., 2020). In Malaysia, Islamic universities are trying to integrate religion and science but with the concept of Islamization, as IIUM has done (Hanafi, 2021). Islamization of knowledge is also being undertaken by Islamic universities in Nigeria but faces serious challenges, including the lack of a universally acceptable model of Islamization (Adebayo, 2016). In Europe, Islamic universities are trying to shift the paradigm from "teaching into" to "teaching about" the teachings of Islam (Berger, 2021). In India, Islamic campuses are also integrating global discourse with Islamicism (Pedersen, 2016). The Islamic colleges in America endeavor to facilitate and condition the formation of a modern Muslim subjectivity, meaning there is an effort to integrate Islam with modernity (Sinclair, 2016).

The description above shows that integrating science and religion in Islamic universities appears diverse, and some still need to make it an important issue. This article portrays Islamic higher education in Indonesia, specifically Syarif Hidayatullah State Islamic University Jakarta, in relation to integrating science and religion. This campus was chosen because it was the first Islamic tertiary institution to transform from the State Islamic Institute (IAIN) to a State Islamic University. Many previous studies have been carried out on this topic; for example, Nurlena Rifai et al. conducted an integration study at UIN Jakarta and several other UINs in Indonesia, the conclusion of which was that the integration of UIN Jakarta did not yet have a form; this is different from that of other UINs, which have a form of integration with metaphorical terms. UIN Yogyakarta uses the term integration-interconnection with a spider's web; UIN Malang uses the term tree of knowledge, etc. (Rifai et al., 2014). Almost 15 years since 2002, the integration of UIN Jakarta has been carried out individually by lecturers, so the integration is still looking for forms.

This view aligns with that of Bambang Suryadi et al., who explored the perceptions of students and lecturers. The results indicate that integration is still experiencing problems. The problems encountered during the implementation of the integrated curriculum include the absence of clear guidelines for implementing the integrated curriculum, the lack of competence of lecturers in carrying out the integration in the learning process, the lack of specific nomenclature regarding the concept of integration, and the limited time allotted when studying Islamic studies in the natural sciences study program. However, students and lecturers positively perceive the integrative curriculum at this Islamic university (Suryadi et al., 2018). This research differs from the results of subsequent studies, which show dynamic integration at UIN Jakarta.

Zulkifli et al. conducted further research to explore integration specifically at UIN Jakarta. The findings show that at UIN Jakarta, knowledge integration is dynamic rather than singular. At least based on this study's results, there are three types of knowledge integration concepts. The first is the official (formal) conception, the second is the conception of senior academics, and the third is the conception of general lecturers (Zulkifli et al., 2020). Unfortunately, Zulkifli et al. only formulated the integration style of senior and general lecturers based on lecturer discussion forums and formal integration needed to be discussed in depth.

Ronald Lukens Bull conducted a study that generally examines the development of Indonesian Islamic universities from a political science perspective (Lukens-Bull, 2013). Lukens-Bull previously also discussed the two sides of Islamic educational institutions in Indonesia, modernity and traditionality, which cannot be separated (Lukens-Bull, 2001). A similar study was also conducted by Florian Polh, who proved that the study of religion in Indonesian Islamic universities was conducted academically and integrated with theological and ethical–political goals. Polh's findings are different from those of previous researchers in the nineteenth century (Pohl, 2015). Islamic universities in Indonesia have undergone modernization, described in Dhofier's terms as intellectualization (Dhofier, 1992). Elisabeth Jackson emphasizes that Indonesian Islamic higher education has successfully integrated Western concepts and values with Islam, especially in civic education (Jackson, 2007). Although these studies are about Islamic universities in Indonesia, this article differs from previous studies because it specifically examines the policy and pattern of scholarly integration, which is focused on UIN Jakarta. The pattern of integration described in this article differs from the Islamization of science, as previously mentioned. This article contributes to framing the integration of science and religion with an open integration pattern that Islamic universities in Indonesia and the world can develop.

## Conception of integration

Integration is a term that comes from English and refers to mergers, unification, or integration. In Arabic, it is often called *al-wahdah*; there is also *takamul al-ma'rifah*, which specifically reflects the integration of knowledge. This term is usually used to combine or bring together something different or contradictory. The Encyclopaedia Britannica explains that this term exists in various disciplines, such as mathematics, economics, and business.

In a philosophical context, this term is often about the relationship between religion and science.

In general, the relationship between religion and science is conflictual and often, the conflict is content-dependent and related to religious/non-religious social identities (Leicht et al., 2022). Ted Peters explains the relationship between science and religion in 10 models, but the relationship can be simplified into three parts: war, then truce, and partnership (Peters, 2018). Meanwhile Ian G. Barbour divides this relationship into 4 parts, namely, conflict, religion, and science cannot meet, and they reject each other. Second, in an independent relationship; both run without regard for the other. In the three dialogues; the two can discuss each other but cannot meet, and in the last integration; the two can discuss and meet or unite (Barbour, 2000, pp. 7–34).

Furthermore Ian Barbour explains the concept of the integration of science and religion in 3 forms, namely, natural theology (God's existence can be known through natural design), theology of nature (theological knowledge lies outside science, but science can reconstruct religious doctrines such as about creation and human characteristics), and systematic synthesis (science and religion can contribute to each other in the development of inclusive metaphysics) (Barbour, 2000, pp. 28–34).

Some scholars consider Ian Barbour's three ways insufficient to integrate religion and science. Laura Rediehs completes this by adding one more way, namely, recognizing that religious belief has experiential sources, and this source of experience can become an object of study that can be included in the empirical area (Rediehs, 2022). By conducting an empirical study, religious beliefs can be studied scientifically and integrated with modern sciences. Here, Rediesh tries to formulate the integration of science from an expanded empirical epistemological basis. In addition, Renato Coletto added an approach related to the relationship between religion and science, namely, the reformation approach (Coletto, 2013).

Amin Abdullah emphasizes that integrating science and religion because of scientific linearity is considered to have weaknesses. According to him, the linearity of limiting the field of science narrowly will encourage religious understanding and religious interpretations that are not relevant to the study. At the same time, scientific integration encourages multidisciplinary, interdisciplinary, and transdisciplinary approaches (Abdullah, 2014). In this case, scientific integration (science and religion) is a solution to the relationship between the two, which is always contradictory and monodisciplinary. In simple terms, integration is an approach that can be used to combine religion with science.

The integration of knowledge is an effort not to separate interrelated knowledge. The development of science in the future cannot be carried out individually or in combination with each other science or language with scientific linearity. The world of science is already leading to the unity of science. This is among what Syed Ahamed strives for in his book on scientific change. Syed Ahamed tries to design artificial intelligence to address social and environmental problems coherently, systematically, and optimally. He built his knowledge design by bringing together principles from computer science, electrical engineering, communication science, mathematics, social sciences, and several other related sciences. He wanted to show that a multidisciplinary approach is an approach for future science development (Ahamed, 2017).

The concept of the integration of science and religion is very diverse and dynamic. This concept began to surface in the postcolonial era. History shows that colonialism was among the factors that led to the dichotomy between Islam and science. The Islamization of knowledge is a concept that was initially discussed by scholars who wanted to combine science and religion. Malaysian Islamic campuses, such as the IIUM, have developed the

Islamization of knowledge. Muhammad Naguib al-Attas was among the first to initiate this process, based on his criticism of secularism, which has taken root in the modern era (Al-Attas, 1985). This idea continues to be popularly developed by Ismail Raji al-Faruqi in his book *Islamization of Knowledge* title (Al-Faruqi, 1987).

This idea drew criticism in its development, such as Ziauddin Sardar criticizing al-Faruqi's idea of Islamization due to Westernization (Sardar, 1998). Kuntowijoyo rejected the term because Islamization is a movement from context to text. He proposed the concept of "pengilmuan Islam," moving from text to context (Kuntowijoyo, 2006, pp. 1–3). Indeed, in terms of the application of Islamization, there are still some problems, as noted by the Islamic University of Nigeria, which feels that they have not succeeded in developing the concept because there is no model yet (Adebayo, 2016).

Hossein Nasr and Ziauddin Sardar also share the idea of Islamization. Both depart from the concept of "Islamic science," which is an intellectually and economically progressive scientific endeavor that is inherently ethical and environmentally friendly. This concept is different from the concept of science from the West in that it does not accept reductionism or Western scientific approaches. Nasr and Sardar, for their formulation, intended to overcome most of the problems of materialism and spiritualism. Syed Mehboob Bukhari criticized this idea of Islamization as reasonable but highly impractical, utopian, and simplistic. The reason is that Islamic science cannot be separated from Western science and is vulnerable to the reasonable control of the global capitalist system. The concept of Nasr and Sardar is vulnerable to the commodification of hegemony against global capitalism (Bukhari, 2019). In the Indonesian context, the Islamization of science has received little attention. Islamic scientists and universities have developed the concept of "integration of science," which is used to integrate Islam and science. UIN Syarif Hidayatullah Jakarta is among the pioneers of this.

## Research methods

This research uses qualitative methods and is a field study focused at Syarif Hidayatullah State Islamic University Jakarta, Indonesia. The method of data search is by interview and documentation. The research participants as primary sources are Prof. Asep Saefuddin Jahar, director of the graduate school 2019–2023, now the University Rector for the period 2023–2027, Prof. Yusuf Rahman as Deputy Director of the Graduate School 2023–2027, previously as Dean of the Faculty of Ushul al-Din, then Prof. Didin Saefuddin as Chair of the Graduate School Doctoral Program for the period 2015–2023, and Prof. Husni Rahim as one of the senior lecturers. Interviews were conducted 2021 with Prof Husni Rahim and the rest in 2023. All resource persons were previously informed that the interviews were for research purposes, whose results would be published and did not mind being quoted by name. The interviews were semi-structured, in which the researcher prepared a list of questions for the resource persons, but the questions were also developed outside the existing list.

The primary sources in the form of documents are the rector's policy as stated in the Decree of the Rector of UIN Syarif Hidayatullah Jakarta Number: 864 of 2017, concerning Guidelines for the Integration of Sciences of UIN Syarif Hidayatullah Jakarta and the academic guidelines of UIN Syarif Hidayatullah Jakarta 2018/2019 and 2019/2020. Other primary sources are the works of lecturers related to the integration of science and its application. Among the lecturers whose works are used as sources of study are Prof. Harun

Nasution, Prof. Mulyadhi Kartanegara, Prof. Atho Mudzhar, Prof. Suwito, Prof. Masykuri Abdillah, Prof. Armai Arif, Prof. Abbudin Nata, Prof. Azyumardi Azra, Prof. Didin Saefuddin, and Prof. Andi Faisal Bakti. Secondary sources are also used, namely, previous research related to the theme of this research.

The theoretical approach used in this study is integration theory. This theory is an approach to integrating two different things. As in Ian Barbour's theory, the relationship between religion and science is divided into four parts: conflict, independence, dialogue, and integration. The previous discussion has explained this. Integration is an approach to integrating science and religion whose previous relationships were conflictual or independent. The framework for the integration of science and religion then becomes the reference in this study.

## Integration at UIN Syarif Hidayatullah Jakarta

UIN Jakarta was first established on 1 June 1957 under the name of Akademi Dinas Ilmu Agama (ADIA) by the Ministry of Religious Affairs of the Republic of Indonesia to prepare functional Islamic religious teachers by the demands of modernity. In 1960, ADIA was integrated with the existing Islamic Religious Higher Education (Perguruan Tinggi Agama Islam/PTAIN) in Yogyakarta and changed its name to the State Islamic Institute (IAIN) al-Jamiah al-Islamiyah al-Hukumiyyah held in Yogyakarta and Jakarta. Based on the Decree of the Minister of Religious Affairs of the Republic of Indonesia No. 49 of 1963, the institution was designated as two IAINs, which in Jakarta changed its name to IAIN Syarif Hidayatullah Jakarta. This change from ADIA to IAIN was in response to developing high public interest and establishing diverse faculties. IAIN Jakarta not only studies religious sciences but also organizes general science study programs such as psychology, mathematics education, economics, and Sharia banking study programs in 1998/1999, although still within the Faculty of Tarbiyah (Islamic education) and the Faculty of Sharia. At that time, this was an effort to integrate religious and general sciences at IAIN, called "IAIN With Wider Mandate." In 2002, IAIN Jakarta was officially transformed into UIN Jakarta, whose main goal was to integrate religious and general sciences. Other IAINs then followed this transformation (*Academic Guidelines for Undergraduate Programmes of UIN Syarif Hidayatullah Jakarta 2018 / 2019 and 2019/2020*).

The development history above shows that the vision of integration at UIN Jakarta was started when it was still ADIA. Then, it began to develop when it was transformed into IAIN. In this case, Abdullah Saeed calls it the integration of Islam with the spirit of modernity (Saeed, 1999). Integration, in this case, can be said to be substantive integration. Integration formally became the institution's vision after transforming into a State Islamic University. Husni Rahim, one of the senior lecturers, asserted that integrating the sciences was the ideal of previous figures, such as Harun Nasution, who established a postgraduate institution (now the Postgraduate School) (personal communication, November 10, 2021). This idea was eventually realized formally by changing the nomenclature from institute to university so that general faculties could be established under the name of the State Islamic University.

Asep Safuddin Jahar, who is currently the Rector of UIN Jakarta (2023–2027), said that the integration of science at UIN Jakarta involves studying not only Islam normatively but also Islam historically. Integration is also in the form of multidisciplinary science and attempts to dialogue with it. People whose basis is not from religious science (*naqliah* science) can study here. UIN Jakarta Postgraduate School is among the institutions that realize the integration of science (personal communication, February 21, 2023).

It should be noted that the realization of science integration found its momentum after the lecturers studied abroad, namely in the West. In Dhofier's terms, this is called the intellectualization process (Dhofier, 1992). This process was carried out long before there was a State Islamic University. This means that the preparation for formal integration is preceded by the preparation of human resources who have experience learning from the West. Didin Saefuddin, Head of the Doctoral Study Programme at UIN Jakarta Postgraduate School (2015–2023), confirmed that Harun Nasution was among those who played an important role in preparing these human resources. Harun Nasution advised lecturers studying in the West to take different concentrations of certain sciences. According to Didin Saefuddin, Harun Nasution hoped that this Islamic higher education institution could synthesize Islamic civilization from the Middle East and the West (personal communication, January 19, 2023). Yusuf Rahman added that those instrumental in providing advice and recommendations for the concentration of knowledge to be taken by lecturers studying in the West were Atho Mudhar, Fuad Jabali, and Azyumardi Azra. This was all to prepare IAIN with a wider mandate. This term was before IAIN transformed into UIN. According to Yusuf Rahman, the purpose of meeting alums from the West and the Middle East at UIN Jakarta is to support the integration program (personal communication, January 20, 2023).

Scientific integration in the case of UIN Jakarta has run gradually since the beginning of its development. From the beginning of its development, integration at UIN Jakarta can be considered open integration, namely, integration whose implementation is left to each lecturer. However, in its development now, it has a formal concept, meaning that there is already a standard concept that is a shared guide by lecturers. In addition, what needs to be recognized is the integration of senior lecturers and the integration of lecturer aspects (human resources). The following is a detailed and in-depth explanation.

## Integration from open to formal

The basis for the transformation of IAIN to UIN is Presidential Decree No. 031, dated 20 May 2002, with the main objective of integrating religious and general sciences. The first rector was Prof. Azyumardi Azra (1998–2006), followed by Prof. Komaruddin Hidayat (2006–2014), Prof. Dede Rosyada (2015–2018), Prof. Amany Lubis (2019–2023), and Prof. Asep Saefuddin Jahar (2023–2027).

At the time of its reintegration (in 1998–2006), the concept used as the basis was to reintegrate the sciences, which were considered a dichotomy between religious knowledge and general science. This reintegration is, of course, a concept used to indicate that it has succeeded in integrating knowledge in the history of Islamic civilization. The time to do the same thing is called reintegration (Azra, 2013a). The term "religious knowledge in the IAIN period," before it became UIN, was applied in a very narrow sense and was detrimental to the development of the sciences themselves; this was one of the underlying reasons for reintegration (Azra, 2000).

The paradigm of knowledge integration is based on faith, knowledge, and good behavior. Philosophically, this reintegration includes overcoming the problem of the scientific dichotomy that occurs between religious knowledge and general science. Therefore, by changing the IAIN to the UIN, public faculties will be opened. This concept was strengthened by the publication of a book titled *Integration of Religion and General Science* written by Abuddin Nata, Suwito, Masykuri Abdillah, and Armai Arief (Nata et al., 2005).

During the Rector's era, Komarudin Hidayat (2006–2015) described the form of knowledge integration as described in the campus motto, namely, "knowledge, piety, and integrity." In the period 2015–2019, when the Rector was Dede Rosyada, the concept of integration was formulated with members of the Senate, the results of which were stated in the Decree of the Chancellor of UIN Jakarta No. 864 regarding the guidelines for the integration of knowledge. These guidelines will become a reference for all academics and all institutions and faculties to postgraduate schools.

The concept of integration contained in the Decree of the Chancellor of UIN Jakarta No. 864 is a guideline that has never existed before. This decree consists of 16 articles, from the first article on general provisions to the closing articles. Specifically, the concept of integration can be seen from Article 2 to Article 12 as related to the meaning, goals, objectives, knowledge clusters, and strategies for integrating each scientific family. The integration of knowledge is interpreted as the unification of Islamic religious knowledge with other sciences so that they are not contradictory or dichotomous. This meaning is emphasized not in the form of Islamization of knowledge (Decree of the Rector of UIN Syarif Hidayatullah Jakarta Number: 864/2017).

The integration of knowledge is intended so that the integration of religious sciences and other sciences occurs, after which new knowledge can be developed through new study programs and professionals in more diverse fields can increase international cooperation and gain recognition from the international academic community. There are 6 clusters of knowledge categorized in this decision: religious sciences, humanities, social sciences, natural sciences, formal sciences, and applied sciences.

There are two main strategies for integrating these sciences: for the Islamic religious sciences to be strengthened by the relevant general sciences. On the other hand, general sciences are given reinforcement that is relevant to Islamic sciences. In particular, this strategy is described in Article 7 concerning the integration strategy of the Islamic religious sciences. Article 8 on the integration of humanities, Article 9 on the integration of social sciences, Article 10 on the integration of natural sciences, Article 11 on the integration of formal sciences, and Article 12 on the integration of applied sciences.

After the publication of the letter, the head of the Senate at that time, Prof. Dr. Atho Mudzhar, welcomed it by writing a long note published by the University Senate under the title "The Integration of Science and Religion in Search of a Paradigm." As an introduction, Atho Mudzhar emphasized that the integration of science is the final stage among the five possible relationships between religion and science. The five possibilities are conflicting relationships, mutually exclusive relationships between religion and science, relationships in the form of Islamization of science, dialogic-interactional relationships even though religion and science are not mutually supportive, and ultimately, integrational relationships (Mudzhar, 2018, pp. 2–3).

Atho Mudzhar further explained the position of Islamic studies within the humanities and social sciences. UNESCO categorizes science into three parts: humanities, social sciences, and natural sciences. The purpose of integrating Islamic religious sciences is to integrate science and religion. In this case, Atho Mudzhar cites the views of Goode and Hatt a lot. Here, religion in Islam is interpreted as a collection of doctrines and values. Therefore, the integration of Islam and science means the integration of knowledge and Islamic values (Mudzhar, 2018, p. 7).

All knowledge is susceptible to value, even if it is a natural science. In substance, natural science can be said to be free of value, but philosophy and its goals or the motives of researchers to take the object of study are still vulnerable to values. Here, Atho Mudzhar divides the function of knowledge into two parts, namely, core knowledge and auxiliary knowledge. Assistive science here does not mean that it will reduce the depth of the core knowledge but can enrich or broaden studies, for example, medical sociology. As an auxiliary science, this science does not mean that it will reduce the depth of medical knowledge for prospective doctors but can enrich it.

Integration of Islamic values with science can be performed via a two-way approach involving core and auxiliary science. The first direction is from secular sciences to Islamic sciences, and the second is from conventional Islamic sciences to secular sciences. This second direction of inquiry has made secular sciences/sciences auxiliary to conventional Islamic sciences their core knowledge (Mudzhar, 2018, pp. 10–12).

The way to integrate religious sciences with general sciences by the decree on integration guidelines contains several principles, namely, general sciences as material for discussion/dialogue with the Islamic sciences, general science as an inspiration for the development of Islamic sciences, and the general science cluster as a perspective and make the general science cluster as a practitioner of Islamic values for the benefit of humankind. This principle is stated in Article 7.

This way of integration is different if the core is general knowledge. The guidelines describe nine essential principles for integrating the social, humanities, natural, and formal sciences. This principle is explained in Articles 8, 9, 10, and 11. The principle is to rectify the philosophy and goals of science; develop and enrich the theory, substance, and object of study; revise or formulate a new theory; rebuild auxiliary sciences; direct research themes; provide Islamic values as a reference for the application of knowledge; increase the number of science developers who have an integrative perspective; increase the number of relationships and common ground between science/general knowledge and the texts of the al-Qur'an and hadith; and make the text of al-Qur'an hadith an inspiration or source of reference for the development of science.

The concept of integration that needs to be underlined from the decree above is not the Islamization of knowledge. This indirectly rejects the concept of Islamization of science to integrate the sciences. In his description, Atho Mudzhar omits the Islamization of science as part of the concept of integration but as part of the relationship between science and science. These five relationships differ from those of Ian Barbour, who omits Islamization as part of the relationship between science and religion. This means that the integration conceptualized by UIN Jakarta has a clear position among existing concepts about the Islamization of knowledge or other integration models. Dede Rosyada explained that scientific integration allows the realization of dialogic interactions from various kinds of knowledge, including science and religion. In addition, integrating knowledge allows an appreciation of knowledge diversity (plurality) (Rosyada, 2016).

At the beginning of the decision, the letter also explained the classification of science; there are 6 (religious sciences, humanities, social sciences, natural sciences, formal sciences, and applied sciences). This precise classification is by Law No. 12 of 2012 Article 10 concerning higher education. This approach is different from UNESCO, which classifies three sciences, namely, the social sciences, cultural sciences, and natural sciences, but the UNESCO classification is automatic. The six classifications of knowledge described in the Decree can show recognition of the epistemological basis of each of these knowledge groups. The science of religion here is recognized as part of a separate scientific family, while religious knowledge is not recognized scientifically in the West. In the West, religious studies must be approached with sociocultural sciences to be categorized as scientific. In brief, religion in this integration guide is understood not only as religious belief (theology) in which there are sources of value but also as part of science and religion as civilizations.

The Decree on integration simplifies the six knowledge clusters into two sections, namely, religious knowledge and general science. This separation is based on the previous root of the problem regarding the dichotomy of science. Furthermore, the importance of integration implementation must determine the importance of core knowledge and auxiliary science. The role of assistive science can strengthen the analysis or become an inspiration to add and develop analyses or find conclusions related to the methodology. If the auxiliary science is general knowledge, then the core knowledge is religious.

On the other hand, if auxiliary science involves religious knowledge, then the core knowledge is general knowledge. Using Ian Barbour's term, religious knowledge and general science can be included in dialogue and integration Although Atho Mudzhar, in his description of the natural sciences, says that it is challenging to integrate religious values or knowledge, what is evident based on these guidelines, this can happen.

Religious knowledge and other sciences here are equal; the two can blend, discuss each other, and strengthen, enrich, or provide inspiration. This differs from the Islamization concepts of Nasr, Sardar, al-Attas, and al-Faruqi, who consider Western science the antithesis of Islam itself. The equal position of the religious sciences, in this case, that *naqliah*/classical/conventional Islamic sciences can be understood with other sciences, shows that there is epistemological recognition of the two kinds of knowledge. However, in the practice of integration, each can act as a core or auxiliary science. Integration is not just combining knowledge; more than that, it means giving birth to new knowledge, discoveries, and new professionals; bringing up scientific disciplines; and international cooperation.

The UIN Jakarta integration guidelines are a primary reference for lecturers conducting research and teaching and for mentoring students. The concept of integration is, of course, the general basis, where the implementation is based on the development of the creativity of lecturers and students. At the Postgraduate School of UIN Jakarta, special courses, namely, the Islamic Study Approach Methodology course, encourage integrative studies in the context of Islamic studies. Separately, other courses, such as elective courses or specializations, are encouraged to strengthen students in carrying out the integration.

The description above shows that UIN Jakarta's integration concept has a clear pattern of positioning religious and general sciences into core and auxiliary sciences and is strictly not Islamization. This is different from what Nurlena Rifai and Suryadi convey: the integration of UIN Jakarta does not have a form and nomenclature (Rifai et al., 2014; Suryadi et al., 2018). If traced from the beginning of its development, the concept of integration is only contained in the vision and mission in general, the implementation of which is left to the lecturers and then formed in a Decree during the period of the Rector Prof. Dede Rosyada until now. This is also in line with Zulkifli et al. in describing the concept of official integration based on the statute and the vision of the rector from Azyumardi Azra, Komarudin Hidayat to Dede Rosyada. Based on the statute, which is the basis for the transformation of IAIN to UIN, the vision of integration is to combine science, Islamic teaching, and Indonesian values. This is done in order to become a world-class university. Then, each rector tries to implement it, and it can be seen that each has made an effort (Zulkifli et al., 2020). Again, integration in this official concept provides principle guidance for lecturers and students so they do not become trapped in the Islamization of science or labelling. As for the implementation and development, each lecturer and student is given freedom.

## Integration seen from the lecturers' works

The conception of integration at UIN Jakarta, apart from the official institutional aspects described above, can also be seen from the perspective of lecturers' works. This conception can show the integration lecturers implement in conducting research/studies.

The first thing that needs to be presented is the work of the founder of the Postgraduate Program at UIN Jakarta, namely, Prof. Harun Nasution, who is known as a reformer of Islamic thought in Indonesia (Filsafat, 1989). He produced many works, but the one that is popular is the content with the nuances of integration, namely, his book titled *Islam Viewed from Its Various Aspects*. This book consists of two volumes, first published by UI Press in 1974, and volume 2 was first published by the Bulan Bintang Jakarta publisher in 1974. Regarding the role of Harun Nasution, you can read the impressions of his students or those close to him (Suwito & Abdullah, 2016). In subsequent printings, volumes 1 and 2 were published by UI Press (Nasution, 1985). This book became a mandatory manual for IAIN students at that time, not only in Jakarta but also at other IAINs. There are no students who do not recognize him. Students who have never read the book and do not even know it can be said to be not the main student of IAIN.

Harun Nasution explicitly stated his anxiety about the birth of this book. The anxiety is that Islam, which Indonesian people understand, seems narrow. According to him, this can happen inseparable from the Islamic religious education curriculum, which emphasizes only aspects of worship, jurisprudence, monotheism, interpretation, hadith, and Arabic. In general, this aspect can be summarized into three aspects, namely, worship, fiqh, and monotheism, and, even then, only certain schools of thought. This ultimately seems narrow, whereas the aspects of Islam are comprehensive, according to Harun Nasution.

In addition, there is a practical matter underlying the book; in August 1973, a working meeting of IAINs throughout Indonesia was held in Bandung, which decided to add a new course, namely, Introduction to Islamic Studies, to the current curriculum. The previous curriculum system led students to enter particular fields (specializations) so that they could understand Islam comprehensively. In addition, no literature in Indonesia discusses Islam from various perspectives.

From this background, it is evident that the purpose of writing this book is that Harun Nasution wants to introduce Islam comprehensively. Harun Nasution systematically tries to provide a multiperspective description of Islam that is not limited to aspects of worship, fiqh, and monotheism. In addition, it presents diverse opinions and refers to classical Islamic works (truth), contemporary Islamic works, and works by Westerners who speak English. Although not thick, Harun Nasution's work tries to integrate various perspectives and various sources of reference. From here, the concept of comprehensive Islam developed and was once the name of a compulsory subject.

According to Megan Brankley Abbas, Harun Nasution is a fusionist character representing the Institute of Islamic Studies (IIS), McGill. The character of the fusionist is the opposite of the dualist who contrasts Islam with the modern (Western) world or vice versa, and the West opposes Islam. The fusionist character that Wilfred C. Smith, the founder of IIS McGill, aspired to (Abbas, 2021). The IIS McGill campus is certainly not the only factor that has shaped the Harun Nasution to have a fusionist character or, in this subreferred to as integrative. However, there are other factors, such as his previous educational background. However, at least IIS McGill influenced him academically.

Among his students who continued the idea of comprehensive Islam was Abuddin Nata. He is one of the senior lecturers who wrote a book titled Comprehensive Islamic Studies

(Nata, 2011). This book illustrates that Islam is complete, not only in terms of revelation (*qawliyah* verses) but also in relation to *kawniyah* verses. Abuddin Nata was very prolific in writing, and many works were born with integrative nuances, including one entitled Sociology of Islamic Education (Nata, 2016). This book attempts to examine Islamic education from a sociological perspective.

Among his other works related to integration is entitled Methodology of Islamic Studies (Nata, 2006). This book describes models of Islamic studies from classical to sociocultural science models. Specifically, relating to how to carry out the integration was written with Professor Suwito, Professor Masykuri Abdillah, and Professor Armai Arif entitled *Integration of Religious Sciences and General Sciences* (Nata, 2006). Based on these works, Abuddin Nata et al. state that Islam is holistic and comprehensive. Therefore, their books explain the revealed sciences *(qawliyah)* and modern sciences *(kawniyah)*, the relationship between the two, and how to integrate them. In addition, Didin Saefuddin wrote a similar book on the methodology of Islamic studies, and he served as the Head of the Graduate School's Doctoral Study Program (2015–2023). Although small, the book he wrote discusses Islamic studies from the perspective of classical Islamic sciences to social science-humanities approaches. This book was written to convey an integral understanding of Islam (Buchori, 2012).

The next is the book *Introduction to Islamic Studies*, the second compulsory book, a continuation of the book written by Prof. Harun Nasution. Professor Mulyadhi Kartanegara, a senior lecturer at the Postgraduate School of UIN Jakarta, edited this book. He wrote many works and is also the coordinator of teaching Islamic and science courses. This book reflects the author's perspective in viewing the scope of Islamic studies. This edited book consists of 12 authors and 16 chapters. In addition to being an editor, Mulyadhi Kartanegara contributed eight chapters from chapter 8 to chapter 16, except for chapter 12. Moreover, chapters 1–7 were written by other authors.

The background for writing the book departs from the weakness of the book Islam, which was viewed from its various aspects by Harun Nasution. Harun Nasution's book is considered second to none for comprehensively introducing Islam and has become a mandatory book in UIN Jakarta. Almost all academics of Islamic studies may not know about him even though his book is very concise. He addressed these deficiencies because the book needed to examine the relationship between Islam and science, mathematics, medicine, and others. Therefore, the book Introduction to Islamic Studies was completed as an answer.

From these 16 chapters, the repertoire of classical Islamic sciences and studies of science, mathematics, medicine, and others have been discussed. Compared to Harun Nasution's book, it is complete because it covers the sciences such as mathematics, psychology, politics, and medicine. However, this book still needs a chapter that discusses information science and technology, which is now highly needed.

In addition to this book, Mulyadhi Kartanegara has written many books or papers on integration methods. The book that discusses this theme explicitly is *Integration of Knowledge: A Holistic Reconstruction* (Kartanegara, 2005). This book offers a way to integrate sciences that are considered contradictory, namely, science and religious knowledge or worldly knowledge. According to him, the integration of sciences does not necessarily combine theories from the West and Islam because of differences in their theoretical basis. Therefore, integration can start from an epistemological basis; the source of knowledge is the methodology, ontology is related to the object of research (object of science), and axiology is related to the values of science.

Furthermore, a book titled Approach to Islamic Studies in Theory and Practice was written by M. Atho Mudzhar (Mudzhar, 2011). This book was printed several times by the Pustaka Pelajar and was first printed in 1998. This means that this book was printed before a State Islamic University but was still a State Islamic Religious Institute. This book is meant to be a continuation of the book written by Harun Nasution about Islam in terms of its various aspects. The author is aware that Islamic study methods have been developed within the IAIN environment, but conventional methods have been developed. This method revolves around the study of al-Qur'an *('ulum al-Qur'an)*, the study of hadith *('ulum al-hadith)*, and the study of fiqh as well as usul al-fiqh.

This conventional method is said by Atho Mudzhar to be alien to contemporary scientific methods, even though it is possible to find an equivalent with the social science-humanities method. In addition, in the 1980s, the IAIN curriculum already had courses in Islamic studies that tried to introduce scientific and contemporary methods of Islamic studies. In this course, the book used as a guide is a book written by Harun Nasution. However, in practice, this course does not introduce scientific methods in Islamic studies but rather introduces/deepens Islamic material from various aspects. Therefore, this course still needs to provide a guide for students to understand Islamic studies with contemporary scientific methods. The subsequent development following the opening of the Master's programme was the Islamic Studies approach course. This course is intended to equip students with scientific study methods.

The book by Atho Mudzhar is meant for that, although in its development, this course is also open to the undergraduate level. Atho Mudzhar explained that Islam could be studied with contemporary scientific approaches such as social research methods and cultural research. According to him, Islam, in this approach, is considered a cultural and social phenomenon. Therefore, social science and cultural science approaches can be used. Here, Atho Mudzhar refuses that Islam can be studied with the approach of natural sciences. The reason is that Islam is not a recurring natural phenomenon. Through this book, Atho Mudzhar offers theoretical and practical Islamic studies conducted using social and cultural science methods.

According to him, five symptoms of religion can be the object of social and cultural science research. The first is related to religious texts, symbols, and scriptures. The second is related to religious leaders, leaders, and practitioners. The second symptom is related to the attitude, behavior, and appreciation of adherents. The third factor is related to rituals, institutions, and worship, such as fasting, praying, pilgrimage, marriage, and inheritance. Fourth, tools such as mosques, churches, caps, bells, and others are needed. The five religious organizations include the NU, Muhammadiyah, Persis, Protestant Church, and Shia (Mudzhar, 2011, pp. 13–14).

Basically, this approach seeks to enrich Islamic studies, which are not merely conventional methods, so that future Islamic studies can produce new conclusions. Atho Mudzhar encouraged scientific integration in Islamic studies even though he did not accept the natural science approach. Atho Mudzhar also strengthened this concept with the terms "core science" and "adutiliary science" to integrate knowledge (Mudzhar, 2018). Andi Faisal Bakti is a senior lecturer who has tried and succeeded in integrating the science of communication into Islamic studies, especially the science of da'wah. His work on this subject indicates continuing integration (Bakti, 2003, 2005; Bakti & Lecomte, 2015).

In addition, what can be shown again is the work of Azyumardi Azra. Azra has served as a rector for two terms and served as postgraduate director for two terms. He wrote a book about the network of Nusantara scholars (Azra, 2013b). This book comprehensively describes the network of Middle Eastern and Archipelagic scholars in terms of the themes of discussion and the sources used. This book illustrates an integrative way of using knowledge sources and approaches between core and auxiliary approaches.

Apart from the works above, which specifically discuss the theory of integration or those whose discussion involves nuances of integration, the integrative character of the lecturer can also be seen from the variety of themes of the papers produced. Abuddin Nata wrote books on integration theory and those with integrative nuances and books with different themes. This shows the ability possessed and broad insight. Azra is a Professor of history at the Faculty of Adab and Humanities. However, Azra has written many works outside of historical themes, such as education, politics, and Islamic thought.

The explanation above shows that lecturers develop integration into a study book or theory specifically about integration. Even though there are minor differences, some common characteristics can be formulated as follows.

First, integration can be applied because an Islamic study can contain several related themes (from multiple perspectives). From the works of Harun Nasution, Abuddin Nata, and Kartanegara, Islam's scope has continued to expand from the science of religion and sociocultural sciences to the natural sciences. Second, the references used to study related Islamic themes are not just one type of reference but can be cross-referenced; they can include references to *tura>th* books, contemporary books, orientalists or Western works, or relevant sources. These references included balanced sources, data, and information to produce the correct conclusions.

The third, integration can be performed from various sciences because the source of knowledge is one, namely, from God. The knowledge known as *qawliah* (the source of the text of revelation) or empirical science *(kawniyah)* originates from God; therefore, both must be scientifically recognized. Fourth, integration can be performed from a philosophical basis and epistemological, ontological, and axiological from epistemological perspectives, for example, by bringing together different research methods or sources of knowledge. From the ontological side, it brings together empirical, rational, and metaphysical objects of study, and from the axiological side (it brings together knowledge values). The five Islamic studies can be integrated with social and cultural science approaches. In fact, in the conventional Islamic sciences, there are methods of the contemporary sciences; it is just that the terms are different. Therefore, the sociocultural science research approach is straightforward. In this approach, Islam is considered a social and cultural phenomenon.

This fifth form of integration can be said to be the integration of core knowledge and auxiliary science. Conventional Islamic studies can act as a core science or vice versa as an auxiliary science. If the core science is conventional Islamic studies, then the auxiliary sciences are sociocultural. Conversely, conventional Islamic studies can be auxiliary for studying sociocultural sciences, which constitute core knowledge.

The examples of the works described above show that lecturers exhibit integrative characteristics in the context of science. All the lecturers agreed on this point. Having the character of a lecturer like this for the UIN Jakarta does not just happen automatically but through a design that has long been implemented by bringing together various lecturers' educational backgrounds. These efforts are so that Indonesian Islamic studies can escape the chaos of Islamic thought, which is considered stagnant, and become a new axis of Islamic thought. This hope has long been discussed by figures such as Mukti Ali, Nurcholis Madjid, H. Alamsjah, Munawir Sjadzali, Gusdur, and others. Panji Masyarakat Magazine, in issue No. 599 of 1989, discusses the central theme of "Indonesia the New Pole of Islamic Thought" by presenting the thoughts of various figures. The main report in this edition is titled "Indonesia Towards a Center for Islamic Thought" (1989).

This shows that the hope that Islamic studies and Indonesian Islamic thought can become a way out of the stagnation of world Islamic studies/thoughts has long been discussed by Indonesian Muslim leaders. The character of integration in Islamic studies, which UIN Jakarta is currently developing, certainly has something to do with it, and this is not due to just a moment's dynamics but rather departs from long-term dynamics of thought. Integrative Islamic studies are part of an academic effort to overcome the chaos of Islamic studies thus far that they can lead to a new axis of Islamic study models in the world that is distinct from others.

The integration of Islam and science at UIN Jakarta, which can be seen from the official policy and the works of lecturers above, is the fourth relationship between religion and science, according to Ian Barbour, which is an integrative relationship, especially the systematic synthesis pattern (science and religion can contribute to each other in the development of inclusive metaphysics). The pattern of integration of UIN Jakarta, in addition to what has been described above, in the future will continue to develop because the formal integration policy has a principle footing, and the rest in the implementation of lecturers and students are open to developing it.

## Conclusion

Combining religion and science is a debate that still needs to be resolved, including in the Islamic world. Islamization of science is among the responses to the idea of combining Islam and science. Many Muslim scientists have this or similar ideas, such as Ismail al-Faruqi, Naquib al-Attas, Seyyed Hossein Nasr, Kuntowijoyo Ziauddin Sardar, and Islamic universities worldwide. The form of integration of religion and science in Islamic universities is diverse; some are Islamization, integration of religion with the spirit of modernism; some have failed, and there is also an academic orientation of ideologization, as mentioned in the introduction to this study. In the context of Islamic universities in Indonesia, the relationship between religion and science is integrated, although each Islamic university has various patterns or forms. Based on this study, whose object is UIN Syarif Hidayatullah Jakarta, that integration can at least be seen from the concept of official campus integration, which shows the integration of religious sciences with general sciences/core sciences with auxiliary sciences. If the core science is religious, then the auxiliary science is general, but if the core science is general, then the auxiliary science is religious. The official concept of integration explicitly rejects the Islamization of science. Then, integration is seen from the works of lecturers, which can be formulated into five forms, namely, first, integration of scientific themes that have interrelationships (multiperspective); second, integration of references; third, integration can be done from various sciences; fourth, integration can be done from a philosophical basis (epistemological, ontological, and axiological); fifth integration with social science and cultural science approaches. The official integration policy at UIN Jakarta becomes the main principle, and its application and development are based on the lecturers' experience. Based on these findings, it can be said that the pattern of integration at UIN Syarif Hidayatullah Jakarta is open, allowing it to continue to develop by developing the world of education and the creativity of the academic community. This study can contribute to integrating religion and science, especially for Islamic universities in Indonesia and the world. However, this study realizes that there are still limitations, namely not examining integration in terms of student research; therefore, student papers can be examined to see the development of science integration patterns in the future.

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## Declarations

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## References

Abbas, M. B. (2021). *Whose Islam?* The Western University and Modern Islamic thought in Indonesia.

Abdullah, M. A. (2020). *Multidisiplin, interdisiplin, & transdisiplin metode studi agama & studi islam di era kontemporer* (Multidisciplinary, Interdisciplinary, & Transdisciplinary Methods of Religious Studies & Islamic Studies in the Contemporary Era) (2nd ed.). Ib Pustaka.

Abdullah, M. A. (2014). Religion, science, and culture: An integrated, interconnected paradigm of science. *Al-Jami'ah: Journal of Islamic Studies*, *52*(1), 175. https://doi.org/10.14421/ajis.2014.521.175-203

Abunamous, R. (2020). Assessment of security and safety procedures at the Islamic University of Gaza and its impact on the efficiency of emergency management from employees' perspective. *Humanities and Management Sciences - Scientific Journal of King Faisal University*. https://doi.org/10.37575/h/mng/2195

Abunamous, R. E. S., Musalam, A. M. A., & El-Ashgar, N. M. (2020). Emergency management in universities as a case study islamic University Gaza. *International Business Management, 14*(9), 337–345.

Adebayo, R. I. (2016). The challenges of Islamization of knowledge in Nigerian Islamic Universities. *IIUM Journal of Educational Studies, 4*(1), 78–99. https://doi.org/10.31436/ijes.v4i1.40

Ahamed, S. (2017). *Evolution of knowledge science: Myth to medicine: Intelligent internet-based humanist machines*. Elsevier Science and Technology Books, Inc. http://www.books24x7.com/marc.asp?bookid=120125

Akbar, A. (2019). Islam–science relation from the perspective of post-revolutionary Iranian religious intellectuals. *British Journal of Middle Eastern Studies, 46*(1), 104–122. https://doi.org/10.1080/13530194.2017.1383882

Al-Attas, M. N. (1985). *Islām, secularism, and the philosophy of the future*. Mansell Pub.

Al-Faruqi, I. R. (1987). *Islāmization of knowledge: General principles and work plan*. The Institute. https://books.google.co.id/books?id=ERuyOwAACAAJ

Azra, A. (2013a). Islamic education and reintegration of sciences: Improving Islamic higher education. *Media Syari'ah: Wahana Kajian Hukum Islam Dan Pranata Sosial, 15*(2), 263–270.

Azra, A. (2013b). *Jaringan Ulama Timur Tengah dan Kepulauan Nusantara Abad XVII & XVIII Akar Pembaharuan Islam Indonesia* (Perennial) (Network of Middle Eastern and Archipelago Scholars in the XVII & XVIII Centuries The Roots of Indonesian Islamic Renewal (Perennial). Kencana.

Azra, A. (2000). Pengelompokan Disiplin "Ilmu Agama" Perspektif IAIN (Disciplinary Grouping of 'Religious Sciences' IAIN Perspective.. In M. A. Abdullah (Ed.), *Antologi Studi Islam Teori & Metodologi* (Anthology of Islamic Studies Theory & Methodology) (pp. 153–161). Sunan Kalijaga Press.

Bakti, A. F. (2003). Communication and Dakwah: Religious learning groups and their role in the protection of islamic human security and rights for Indonesian civil society. In W. Nelles (Ed.), *Comparative Education, Terrorism and Human Security* (pp. 109–125). Palgrave Macmillan US. https://doi.org/10.1057/9781403982391_8

Bakti, A. F., & Lecomte, I. (2015). The integration of Dakwah in journalism: Peace journalism. *Jurnal Komunikasi Islam, 5*(1), 185–203.

Bakti, A. F. (2005). Mengkaji Islam Sebagai Objek Ilmu Pengetahuan: Tinjauan Interdisipliner Komunikasi (Examining Islam as an Object of Science: An Interdisciplinary Review of Communication). *Perta: Jurnal Inovasi Pendidikan Tinggi Agama Islam*, *7*(2), 27–32.

Banikamal, A., & Ra'ees, W. (2018). Iran's educational diplomacy in the Muslim World: Activities of Al-Mustafa International University in Malaysia and Afghanistan. *Insight Turkey, 20*(1), 165–188. https://doi.org/10.25253/99.2018201.10

Barbour, I. G. (2000). *When science meets religion: Enemies, strangers, or partners?* (1st ed). HarperSanFrancisco.

Berger, M. S. (2021). Shifting Paradigms in Islamic higher education in Europe: The case study of Leiden University. *Religions, 12*(1), 63. https://doi.org/10.3390/rel12010063

Buchori, D. S. (2012). *Metodologi Studi Islam* (Islamic Studies Methodology) (1st ed.). Serat Alam Media.

Bukhari, S. M. (2019). The Islamisation of ʿilm: Ideals and Realities in a Globalised World. In S. Akkach (Ed.), *'Ilm: Science, Religion and Art in Islam* (pp. 98–112). University of Adelaide Press; JSTOR. http://www.jstor.org/stable/j.ctvb4bt41.14

Coletto, R. (2013). Religion, theology and science: A reformational Dooyeweerdian approach. *Theology and Science, 11*(2), 130–142. https://doi.org/10.1080/14746700.2013.780431

Çoruh, H. (2020). Relationship between religion and science in the Muslim modernism. *Theology and Science, 18*(1), 152–161. https://doi.org/10.1080/14746700.2019.1710355

Dhofier, Z. (1992). The intellectualization of Islamic studies in Indonesia. *Indonesia Circle. School of Oriental & African Studies. Newsletter*, *20*(58), 19–31. https://doi.org/10.1080/03062849208729783

Farquhar, M. (2015). *The Islamic University of Medina since 1961: The politics of religious mission and the making of a modern Salafi Pedagogy*. Edinburgh University Press.

Filsafat, L. S. A. (1989). *Refleksi Pembaharuan Pemikiran Islam: 70 Tahun Harun Nasution (Reflections on the Renewal of Islamic Thought: 70 Years of Harun Nasution. Dunia Bulan Bintang)*. Dunia Bulan Bintang. https://books.google.co.id/books?id=7nlTAQAACAAJ

Hanafi, S. (2021). From Streamlining to mainstreaming "Islamization of Knowledge": The case of the International Islamic University of Malaysia. *American Journal of Islam and Society*, *38*(1–2). https://doi.org/10.35632/ajis.v38i1-2.1086

Haron, M. (2016). Muslim higher education in the Southern African Region: From secular tertiary institutions to Darul-'Ulums. In M. Lo & M. Haron (Eds.), *Muslim Institutions of Higher Education in Postcolonial Africa* (pp. 41–61). Palgrave Macmillan US. https://doi.org/10.1057/9781137552310_3

Hossein Khani, A. (2020). Islam and science: The philosophical grounds for a genuine debate: with Majid Daneshgar, "The Future of Islam and Science: Philosophical Grounds"; Biliana Popova, "Islamic Philosophy and Artificial Intelligence: Epistemological Arguments"; Mohsen Feyzbakhsh, "Theorizing Religion and Questioning the Future of Islam and Science"; Ali Hossein Khani, "Islam and Science: The Philosophical Grounds for a Genuine Debate"; and Majid Daneshgar, "Uninterrupted Censored Darwin: from the Middle East to the Malay-Indonesian World." *Zygon*®, *55*(4), 1011–1040. https://doi.org/10.1111/zygo.12646

Indonesia Kutub Baru Pemikiran Islam (Indonesia's New Pole of Islamic Thought). (1989). *Panji Masyarakat*, *1*(599).

Irham. (2022). Al-Taʻlīm al-Islāmī al-maftūḥ ladá KH. Sahal Mahfudz (1937–2014). *Studia Islamika*, *29*(1), 143–188. https://doi.org/10.36712/sdi.v29i1.14657

Jackson, E. (2007). Crafting a new democracy: Civic education in Indonesian Islamic universities. *Asia Pacific Journal of Education, 27*(1), 41–54. https://doi.org/10.1080/02188790601142892

Kartanegara, M. (2005). *Integrasi Ilmu Sebuah Rekontruksi Holistik (Science Integration A Holistic Reconstruction)*. Arasy Mizan.

Keputusan Rektor UIN Syarif Hidayatullah Jakarta Nomor: 864 Tahun 2017 Tentang Pedoman IntegrasiIlmu UIN Syarif Hidayatullah Jakarta (Decree of the Rector of UIN Syarif Hidayatullah Jakarta Number:864 Year 2017 Regarding Guidelines for the Integration of Sciences of UIN Syarif Hidayatullah Jakarta). (2017). https://uinjkt.ac.id/wp-content/uploads/2018/01/30-SK-Nomor-864-tentang-INTEGRASI-ILMU-1.pdf

Kuntowijoyo. (2006). *Islam Sebagai Ilmu Epistemologi, Metodologi, dan Etika* (Islam as Science Epistemology, Methodology, and Ethics ) (2nd ed.). Tiara Wacana.

Kurniawan, S. (2018). Sukarno's thought on the importance of reintegration of religion and science in pesantren education In Indonesia. *Journal Of Indonesian Islam*, *12*(2), 219. https://doi.org/10.15642/JIIS.2018.12.2.219-246

Leicht, C., Sharp, C. A., LaBouff, J. P., Zarzeczna, N., & Elsdon-Baker, F. (2022). Content matters: Perceptions of the science-religion relationship. *The International Journal for the Psychology of Religion, 32*(3), 232–255. https://doi.org/10.1080/10508619.2021.2003111

Lukens-Bull, R. A. (2001). Two sides of the same coin: Modernity and tradition in Islamic education in Indonesia. Anthropology Education Quarterly, *32*(3), 350–372. https://doi.org/10.1525/aeq.2001.32.3.350

Lukens-Bull, R. A. (2013). The politicization of the "apolitical": Islamic higher education in Indonesia. In R. A. Lukens-Bull, *Islamic Higher Education in Indonesia* (pp. 1–20). Palgrave Macmillan US. https://doi.org/10.1057/9781137313416_1

Mahfudh, MA. S. (1999). *Pesantren Mencari Makna* (Pesantren in Search of Meaning)(M. Ja'far, Ed.; 1st ed.). Pustaka Ciganjur.

Mudzhar, M. A. (2011). *Pendekatan Studi Islam dalam Teori dan Praktek (Approaches to Islamic Studies in Theory and Practice)*. Pustaka Pelajar.

Mudzhar, M. A. (2018). *The integration of science and religion in search of a paradigm*. Senate of The State Islamic University of Syarif Hidayatullah Jakarta.

Nasution, H. (1985). *Islam Ditinjau Dari Berbagai Aspeknya* (Islam Viewed From Its Various Aspects) (Vols. 1–2). UI Press.

Nata, A. (2006). *Metodologi Studi Islam (Islamic Studies Methodology )* (10th ed.). Raja Grafindo Persada.

Nata, A. (2011). *Studi Islam Komprehensif (Comprehensive Islamic Studies )* (1st ed.). Kencana.

Nata, A. (2016). *Sosiologi pendidikan Islam (Sociology of Islamic education)* (2nd ed.). Raja Grafindo Persada.

Nata, A., Suwito, Abdillah, M., & Arief, A. (2005). *Integrasi ilmu agama dan ilmu umum (Integration of religious and general sciences)*. Raja Grafindo Press.

Pedersen, G. H. (2016). The role of Islam in Muslim higher education in India: The case of Jamia Millia Islamia in New Delhi. *Review of Middle East Studies, 50*(1), 28–37. https://doi.org/10.1017/rms.2016.73

Pedoman Akademik Program Strata Satu UIN Syarif Hidayatullah Jakarta (Academic Guidelines for the Undergraduate Programme of UIN Syarif Hidayatullah Jakarta) 2018 / 2019. (2018). Biro Administrasi Akademik, Kemahasiswaan, dan Kerjasama UIN Syarif Hidayatullah Jakarta.

Pedoman Akademik Strata 1 (Academic Guidelines for the Undergraduate Programme of UIN Syarif Hidayatullah Jakarta) 2019/2020. (2020). UIN Syarif Hidayatullah Jakarta. https://www.uinjkt.ac.id/wp-content/uploads/2020/03/Pedoman-Akademik-2019-2020.pdf

Peters, T. (2018). Science and religion: Ten models of war, truce, and partnership. *Theology and Science, 16*(1), 11–53. https://doi.org/10.1080/14746700.2017.1402163

Pohl, F. (2015). On the Role of interreligious dialogue in religious studies programs at Indonesian State Islamic Universities. *Journal of Ecumenical Studies, 50*(1), 159–166. https://doi.org/10.1353/ecu.2015.0007

Rediehs, L. (2022). The quaker experiential integration of science and religion. *Theology and Science, 20*(2), 138–155. https://doi.org/10.1080/14746700.2022.2051247

Rifai, N., Fauzan, F., & Bahrissalim, B. (2014). Integrasi Keilmuan dalam Pengembangan Kurikulum Di UIN Se-Indonesia: Evaluasi Penerapan Integrasi Keilmuan UIN dalam Kurikulum dan Proses Pembelajaran (Scientific Integration in Curriculum Development at UINs throughout Indonesia: An Evaluation of UIN's Implementation of Scholarly Integration in Curriculum and Learning Processes). *TARBIYA: Journal of Education in Muslim Society*, *2*(1), 13–34. https://doi.org/10.15408/tjems.v1i1.1108

Rosyada, D. (2016). *Islam dan Sains Upaya Pengintegrasian Islam dan Ilmu Pengetahuan di Indonesia (Islam and Science Efforts to Integrate Islam and Science in Indonesia )* (1st ed.). RM Books.

Saeed, A. (1999). Towards religious tolerance through reform in Islamic education: The case of the state institute of Islamic studies of Indonesia. *Indonesia and the Malay World, 27*(79), 177–191. https://doi.org/10.1080/13639819908729941

Sardar, Z. (1998). *Jihad intelektual: Merumuskan parameter-parameter sains Islam ()Intellectual jihad: Formulating the parameters of Islamic science* (A. E. Priyono, Trans.). Risalah Gusti.

Sinclair, K. (2016). "Liberal Arts are an Islamic Idea": Subjectivity formation at Islamic universities in The West. *Review of Middle East Studies, 50*(1), 38–47. https://doi.org/10.1017/rms.2016.74

Suryadi, B., Ekayanti, F., & Amalia, E. (2018). An integrated curriculum at an Islamic University: Perceptions of students and lecturers. *Eurasian Journal of Educational Research, 18*, 1–16. https://doi.org/10.14689/ejer.2018.74.2

Suwito, & Abdullah, A. G. (2016). *Pengembangan Islam Dan Budaya Moderat* (Development of Islam and Moderate Culture ) (1st ed.). Young Progressive Muslim.

Zainiyati, H. S. (2016). *Desain Pengembangan Kurikulum IAIN Menuju UIN Sunan Ampel : Dari Pola Pendekatan Dikotomis Ke Arah Integratif Multidisipliner-Model Twin Towers (Design of IAIN Curriculum Development Towards UIN Sunan Ampel: From a Dichotomous Approach Pattern Towards Multidisciplinary Integrative-Model Twin Towers)* (2nd ed.). UIN Sunan Ampel Press.

Zulkifli, Z., Nurhayati, C., Ruswandi, B., & Suralaga, F. (2020). Plural Conceptions of Integration of Science and Religion. *TARBIYA: Journal of Education in Muslim Society*, *7*(2), 142–157. https://doi.org/10.15408/tjems.v7i2.18991

Zulkifli. (2015). Qom Alumni in Indonesia: Their role in the Shiʿi Community. In M. Bano & K. Sakurai (Eds.), *Shaping Global Islamic Discourses* (pp. 117–141). Edinburgh University Press; JSTOR. http://www.jstor.org/stable/https://doi.org/10.3366/j.ctt14brz7x.9

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# Computational thinking integrated in school subjects – A cross-case analysis of students' experiences

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ABSTRACT

The integration of computational thinking (CT) into K-12 education offers substantial potential to improve digital literacy and deepen students' understanding across various subject areas. By embedding computational procedures and solution-oriented approaches into traditional curricula, students can develop essential skills that are critical for thriving in an increasingly digital world. However, the effective integration of CT into subject-specific learning poses challenges for educators, largely due to a lack of training and experience in implementing interdisciplinary instructional strategies. This study explores the impact of integrating CT into K-12 education through diverse instructional approaches, including modelling, storytelling, and unplugged activities. The research examines how students' subject knowledge, CT concepts, and practices evolved under each CT integration practice, as well as their acceptance toward CT integrated lessons. The study was conducted in different subjects, including language arts, biology, and physics, and at different grade levels. The technology acceptance model was used as a theoretical framework to understand students' adoption towards the different integration practices. The study revealed that different CT integration practices yield varying impacts on students' attitudes, particularly in relation to their prior programming experiences. Namely, primary school students with prior programming experience display a higher behavioural intention due to a lack of early biases toward programming. Conversely, secondary school students, less familiar with interdisciplinary approaches, initially show less enthusiasm for future engagement. These insights underscore the need for tailored instructional strategies that consider students' prior experiences and the broader goal of preparing them to contribute to a technologically driven society.

## 1. Introduction

There has been a growing attention towards making computer science a fundamental subject in K-12 school curriculum and integrating computational thinking into non-computing school subjects (Mouza et al., 2022). One of the reason for including computational thinking (CT) in the curriculum is that the increasing significance of computing concepts and practices in both the workforce and the professional world (Weintrop et al., 2016). Thus, focusing on building a bridge between the CT skills developed in school and the professional CT-integrated scientific fields (e.g. computational biology, bioinformatics, chem-informatics, computational economics and others) became paramount (Malyn-Smith et al., 2018, pp. 182–186). Moreover, it is believed that the integration of CT into school curriculum and students' engagement with application of computational practices and concepts in K-12 will better prepare them for the demands of twenty-first-century economy and citizenship (Yadav et al., 2017).

From a pedagogical perspective, the thoughtful use of computational tools and skill sets can help to deepen learning of subject content (NRC, 2010). The reverse is also applicable namely that subject content provides a meaningful context or problems within which CT can be practiced (Weintrop et al., 2016). Moreover, CT has the potential to significantly advance students' problem-solving, analytical thinking, data analysis and modelling skills (Barr & Stephenson, 2011; Selby,

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2015, pp. 80–87). Additionally, CT encourages students to think creatively and develop innovative solutions to problems. By integrating CT into the curriculum, schools can help students to enhance their understanding about subject related problems and encourage them to deepen in the subject matter (Cuny et al., 2010; Dong et al., 2019).

Despite the growing interest and the recognition of potential academic benefit of CT for students, the integration of CT into the school curriculum has proven to be a challenging issue. Firstly, discussions around the definition of CT, its place in the school curriculum, and how to best achieve integration have not been settled yet (Lee et al., 2020; Weintrop et al., 2016). Secondly, the lack of reliable and valid assessment tools makes the integration of CT into the curriculum even more challenging (Tang et al., 2020). Furthermore, there is a shortage of qualified teachers with the necessary skills and training to teach CT effectively (Astrachan et al., 2011; Barr & Stephenson, 2011; Yadav et al., 2017). There is a need for comprehensive professional development programs to ensure that teachers are prepared to integrate CT into their curriculum.

This study is part of a larger project which aims to understand the various dynamics related to CT integration into primary and secondary education. Specifically, this study supported four different teachers and schools through practice-oriented research, by developing suitable CT learning objectives for primary and secondary education, as well as teaching and learning strategies fostering the acquisition of these objectives. For this purpose, several CT integration practices were implemented through cross-curricular activities in K-12 within different age groups and different subjects. The impact of different CT integration practices on students' understanding was investigated as well as students' actual behaviours toward the integrated lessons.

## 2. Theoretical framework

Computational Thinking (CT) is widely recognized as an essential skill set involving the application of mathematical concepts and computational methods to solve complex problems. According to the National Research Council (NRC, 2010), CT encompasses a range of skills and techniques drawn from computer science and related fields, including problem decomposition, pattern recognition, abstraction, and algorithmic thinking. These skills enable individuals to approach and resolve problems systematically and efficiently. Selby (2015, pp. 80–87) further refines the concept of CT by focusing on distinct cognitive processes essential for problem-solving and innovation. Selby identifies several key CT skills, including abstraction, decomposition, algorithmic thinking, evaluation, and generalization, emphasizing their application across diverse disciplines. In alignment with these conceptualizations of CT, we employed the cross-disciplinary framework (Tress et al., 2005) to clarify various levels of integration while integrating CT into diverse disciplines. The cross-disciplinary framework operates at a macro level, addressing broader educational concepts such as policies, curriculum development, and systemic changes. Simultaneously, we utilized an adapted SAMR framework (Puentedura, 2010) to underscore micro-level CT integration, which focuses on specific elements like lesson plans or the integration of educational technologies at a more granular level. Together, these frameworks provide a comprehensive approach that spans from broad educational structures to specific instructional implementations.

### *2.1. Macro-level CT integration into context: a cross-disciplinary framework*

Macro-level CT integration focuses on larger-scale concepts, or frameworks referring to educational policies, curriculum development, or systemic changes in an education system. Computational thinking is a cross-disciplinary field that draws on principles from computer science, mathematics, and other fields (Kallia et al., 2021; NRC, 2010). CT skills and practices are also applicable in a wide range of domains and can be used to address a variety of complex problems in fields such as computational biology, computational social science, and computational economics (Malyn-Smith et al., 2018, pp. 182–186). The cross-disciplinary framework we adapt and implement for integrating computational thinking education into the curriculum is based on the work of Tress et al. (2005). They use the terms disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary to describe four different degrees to which cross-disciplinary work integrates the concepts, methods, and knowledge of distinct disciplines. In that order, these categories compose a scale from the least to the most integration (Fig. 1).

*A disciplinary approach* is applied when "research is conducted according to the rules and sets of assumptions of one discipline and by members of this discipline" (Tress et al., 2005, p. 484). Computational thinking is associated with the computer science discipline, but it is not exclusively possessed by computer science. However, by teaching CS as a separate subject, students can gain a deeper understanding of programming concepts, algorithms, and problem-solving techniques which are related to computational thinking. Likewise, in the mathematics discipline, students can use CT skills to break down complex equations or word problems into simpler steps, they can use algorithms and logical reasoning to solve each step and arrive at a solution. In a disciplinary approach, no systematic relations or conceptual exchange occurs between different disciplines.

*A multidisciplinary approach* involves researchers who "work in different academic disciplines that relate to a shared goal but with multiple disciplinary objectives." (Tress et al., 2005, p. 485). There is a very loose form of disciplinary interaction since the disciplines involved have different goals and do not significantly influence one another. Common themes or topics can be used to integrate computational thinking concepts and skills. For example, on climate change topic, students might work together across multiple disciplines, including science, social studies, and computer science, to collect and analyse data including temperature trends, sea level rise (science), develop algorithms for predicting future climate scenarios or design visualizations (computer science), research the economic and political aspects of climate change (social science). By working separately in the same theme, students can reach their own learning goals by using their own specific methods.

*An interdisciplinary approach* involves researchers who "work in several unrelated academic disciplines in a way that forces them to cross subject boundaries." (Tress et al., 2005, p. 485). The concerned disciplines integrate disciplinary knowledge and theory and achieve a common goal. New disciplines and subdisciplines appear such as computational biology, computational economics, and computational social science fields that brings together different disciplines, such as biology, computer science, mathematics, and statistics. To address complex problems in this fields, students used shared theories, methods, and concepts in this field. Computational thinking can be used as a cognitive tool or problem-solving tool across different disciplines.

*A transdisciplinary approach* involves researchers "from different unrelated disciplines as well as non-academic participants […] to create new knowledge and theory and research a common question" (Tress et al., 2005, p. 487). Jantsch (1972) proposed a transdisciplinary approach for universities to overcome the split between science and society. He linked scientific activities at all levels to societal demands and innovations. Integrating non-academic partners (policy makers, school administrators, teachers, business practitioners) to CT integration can bring real-world relevance to the learning process and offer opportunities for students to apply their CT skills in meaningful ways to real-world problems. This can help students see the practical CT applications of their learning and prepare them for future careers.

In this study, we designed **interdisciplinary level** case studies that require students to apply computational thinking skills to solve a subject related problem. For example, students develop a simulation model of cell division, or a decision tree for the Koppen climate system, or a

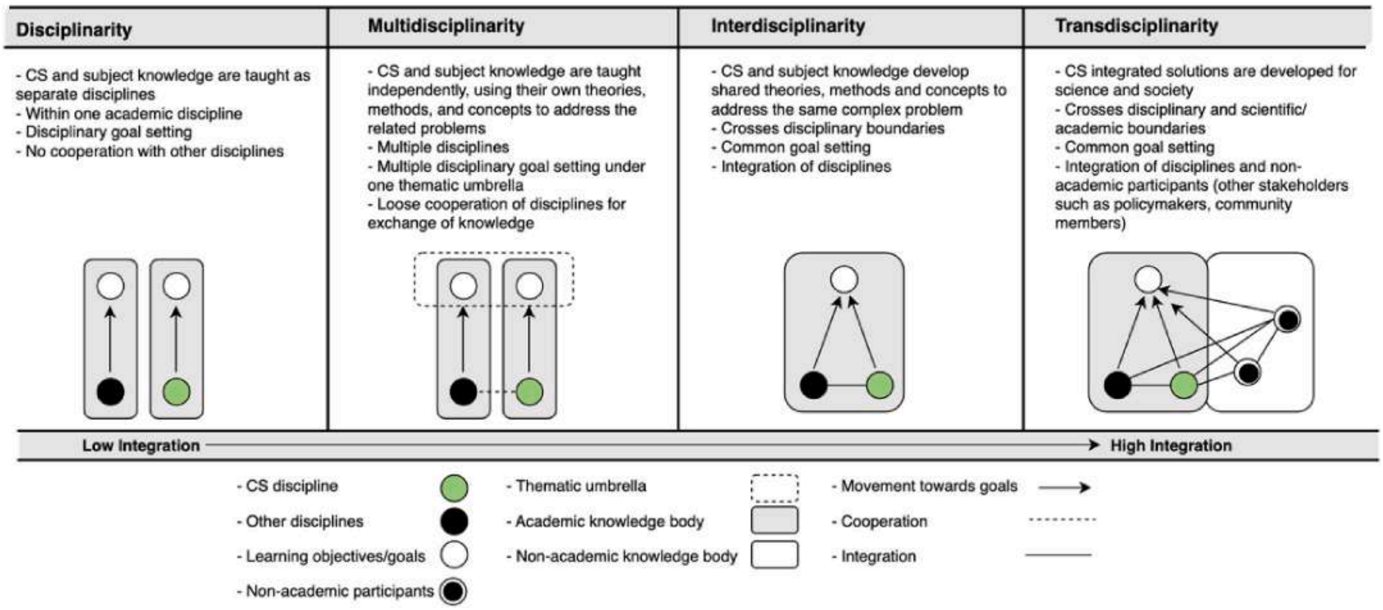


**Fig. 1.** Degrees of computational thinking integration (adapted from Tress et al., 2005).

digital story for a language class, etc. By designing these interdisciplinary projects, we aim to teach students how to apply computational thinking skills to a range of complex subject related problems and develop a deeper understanding of the subject field.

### *2.2. Micro-level CT integration into context: SAMR framework*

Micro-level CT integration focuses on lesson plans, instructional strategies, or educational technologies on a narrow or detailed level. To clarify the micro-level CT integration levels, we adapted the SAMR model (Puentedura, 2010). The SAMR model is a framework used to evaluate the level of technology integration in four levels: Substitution, Augmentation, Modification, and Redefinition (Fig. 2). Here's how the adapted SAMR framework can be applied to micro-level CT integration into context:

*Substitution (Sub):* At the lowest level of integration, CT concepts/models or related tools are a direct replacement for a traditional one. Already existing CT concepts and skills were introduced in the subject lessons with no or limited explanation and CT concepts/skills are not closely linked to subject content. This level doesn't require the use of digital/programming tools. For instance, related to abstraction skill replacing theoretical concepts with tangible representations to understand concepts better, such as, using a three-dimensional manipulative to explore geometric shapes.

*Augmentation (Aug):* At this level, CT concepts/models or lower-level technology act as a direct technology substitute with functional improvement. Teachers enhance the disciplinary content by making a connection to CT concepts. This level also does not require the use of digital/programming tools. For example, replacing the activity of memorizing/recalling different type of cells with the activity of classifying different cell types according to distinctive features of cells using a decision tree.

*Modification (Mod):* At the modification level, it is no longer about enhancement, but the integration provides for transformation. There is an actual change in the design of the lesson and learning outcomes. CT concepts/models or related technology allows for significant task redesign and closely linked CT and subject concepts or skills can be learned with the aim of deeper knowledge and skills. For instance, students run the models to make observations and test their hypothesis and formulate the solutions for their explorations.

Students modify the codes/parameters of model and explain how they expect code changes would impact outcomes.

*Redefinition (Red):* This is the highest level of CT integration, where CT concepts/models or related technology not only transforms tasks but also enables new, innovative interdisciplinary approaches. This level also requires the use of higher-level digital tools/programming tools. For example, creating digital models/simulations previously not available to solve real context-related problems and explore abstract concepts, such as science experiments or historical events.

In summary, the degree of CT integration can be seen as progressing from subject-specific and low-tech substitution and augmentation to more transformative, high-tech, and interdisciplinary modification and redefinition, as conceptualized in the SAMR model.

### *2.3. Instructional strategies for CT integration*

Interdisciplinary learning goals/objectives require instructional strategies that promote collaboration and integration of multiple

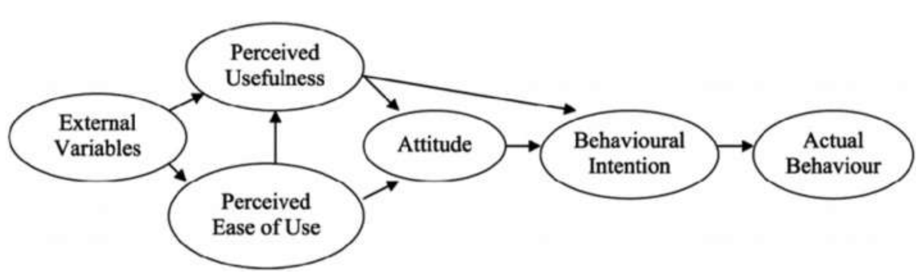


**Fig. 2.** Technology acceptance model (Davis, 1989).

perspectives, methods, and theories to address complex problems and provide a more comprehensive understanding of the subject field. In this study, we used several different instructional approaches that are student-centred, active, and engaging, and that encourage students to develop problem-solving skills and to apply computational tools and methods within different subjects, such as science, language, and social science. Specifically, we implemented three different CT integration practices: modelling, storytelling, and unplugged activities. The reason for choosing these strategies is explained in the 3.2 Lesson Design section.

***Modelling*** involves the use, modification, and creation of digital models to represent and solve problems. While teaching domain subject (kinematics, ecology, epidemic diseases, etc.) students engage in model building, simulation, model checking and verification activities (Basu et al., 2017; Cateté et al., 2018; Hutchins et al., 2018; Louca et al., 2011). First, students read domain specific sources, summarize them, and find common/different properties of data (abstraction), secondly students observe the model behaviours in the form of simulations to explore the deep domain specific problems such as effect of environmental factors on disease spread or ion transport across a cell membrane and then modify or create their own models. Model-based learning is usually combined with Use-Modify-Create approach and students build CT and content knowledge by using, modifying, and creating code in the models (Lee et al., 2011; Lytle et al., 2019; Malyn-Smith et al., 2018, pp. 182–186; Musaeus & Musaeus, 2019).

***Storytelling*** involves the use of narratives to represent and solve problems. By using stories as a basis for learning and problem-solving, students can apply CT concepts in a way that is engaging and relevant to their disciplinary learning. Interactive fiction can provide opportunities to students to apply CT concepts in a subject context by allowing students to make choices and see the consequences of those choices (Göbel et al., 2008; Yeni, Nijenhuis-Voogt, Hermans, & Barendsen, 2022). An interactive fiction story in language arts might involve writing a story with branching paths, using CT concepts to program the story's structure and choices. Additionally, digital storytelling offers students the opportunity to use images and sounds to enrich their storytelling. The use of multi-media not only helps them to express themselves creatively but also enables them to integrate their writing skills with knowledge about digital manipulation and media production (Burke & Kafai, 2010, pp. 348–351). Several studies have examined how using block-based programming (e.g. Scratch) for digital storytelling contributes to engaging students in computational thinking (Burke & Kafai, 2012, pp. 433–438; Parsazadeh et al., 2021; Vinayakumar et al., 2018, pp. 1–6). Furthermore, the use of storytelling is known for improving students' motivation for second language learning (Parsazadeh et al., 2021; Yeni et al., 2022) and for motivating students to learn how to program a computer (Kelleher & Pausch, 2007). Additionally, the role-playing feature of stories can be an effective way to engage students in learning about subject knowledge. By taking on the roles of different characters in a story, students can work collaboratively to solve problems and develop solutions using CT concepts (Chen & Wu, 2021). For example, a role-playing scenario in mathematics might involve narrative-driven challenges which engages students in collaborative problem-solving, reinforcing mathematical concepts in a Mathland Adventure story. Similarly, a role-playing scenario in history might involve designing a game that simulates a particular historical event, using CT concepts to program the game's mechanics and rules.

***Unplugged activities*** involve using non-digital activities, such as hands-on activities and games, to teach CT concepts in a disciplinary context. Many investigations focus on the impact of programming skills or computational media towards learning CT. However, not all teachers are able to implement or teach a programming curriculum at the K12 level (Faber et al., 2017). In this sense, focusing on unplugged activities and pedagogic aspects might help teachers to gain a deeper understanding of how computational thinking can be integrated into various subjects (Bell & Lodi, 2019; Brackmann et al., 2017; Caeli & Yadav, 2020). In this study, we investigated the use of decision trees as an unplugged approach. A decision tree is a decision support tool that uses a flowchart-like model/diagram of decisions and their possible consequences to help identify a strategy most likely to reach a goal (Nijenhuis-Voogt, Yeni, & Barendsen, 2022).

### 2.4. Technology acceptance model

The technology acceptance model (TAM) (Davis, 1985, 1989) is one of the most widely used theoretical models to understand and predict user acceptance of technology/system (see Fig. 2) (Chow et al., 2012; Holden & Karsh, 2010; Yeni & Gecu-Parmaksiz, 2016). TAM is predictive in nature and aims to find the factors that influence people's intentions to use technology/a system. In this study, we used TAM to understand students' actual behaviours toward different CT integration practices: modelling, storytelling, unplugged. TAM comprises core variables of user motivation: perceived ease of use (PEU), perceived usefulness (PU) and attitudes, as well as outcome variables: behavioural intention and actual use (Marangunić & Granić, 2015). PEU is a degree of ease of using particular technology/system and learning without additional effort (Davis, 1989). If people think that new technology is easy to use, their behavioural intention towards using technology becomes positive. PU refers to a positive or negative idea on performance increase in users' tasks as emerged after using technology (Davis, 1989). Further, behavioural intention (BI) can be explained as people's presence to act a specified behaviour. TAM states that behavioural intention of people is the primary factor that determines people's actual use (Teo, 2011). The purpose of this study to apply the original TAM model (Davis, 1989) as a baseline model to examine the students' acceptance of CT integrated lessons. External variables in this study are classified into individual factors: prior experience and programming self-efficacy.

### 2.5. Research aim

The current study investigated different CT integration practices through cross-curricular activities in upper primary and lower secondary education. This study made use of a cross-case research design to examine how students' views and attitudes diverse toward computational thinking integrated lessons within different age groups and different subjects. The study addressed these main research question and sub-research questions:

1. How did students' actual behaviours vary across distinct CT integration practices: Modelling (Modify and Create), Storytelling, Unplugged?
   1.1 What is the perceived usefulness of students toward different CT integration practices?
   1.2 What is the perceived ease of use of students toward different CT integration practices?
   1.3 What is the attitude of students toward different CT integration practices?
   1.4 What is the behavioural intention of students toward different CT integration practices?

## 3. Methodology

### 3.1. Research design

This study is part of a larger project (funded by NRO) which focus on to understand various dynamics of CT integration into the upper primary and lower secondary education curriculum. In particular, this study made use of a cross-case analysis (Merriam, 2009, pp. 39–54) to understand how different computational thinking approaches were integrated into different subjects within different age groups. Case study methodology was chosen for this study because, according to Merriam (2009, p. 50) case study methodology "offers a means of investigating complex social units consisting of multiple variables of potential importance in understanding the phenomenon". Stake (2006) explained that within cross-case analysis, single cases are seen as belonging to a collection of cases that share common characteristics and conditions that are categorically related. In this study, each different instructional strategy constituted a case or cases within our cross-case analysis as different teachers integrated CT in different ways, had different instructional practices about CT, and faced different barriers to implementation.

### 3.2. Lesson Designs

For this study, we examined four different case studies which represent diverse approaches to integrating computational thinking (CT) in the curriculum, namely Modelling-Modify, Modelling-Create, Storytelling, and Unplugged (Table 1). These strategies were selected through collaborative endeavours involving researchers and subject teachers during the design of lesson plans. The selection process considered the learning objectives and needs of teachers, incorporating considerations such as their CT-related pedagogical content knowledge and programming experience. The participating teachers attended workshops where they were shown CT concepts and examples of lessons in which CT was integrated into several disciplines across the curriculum. Then, teachers worked with the researchers individually and developed a lesson plan about a topic they planned to teach anyway, as well as with the level and type of CT they felt comfortable with. These case studies were implemented across two secondary schools and one primary school located in the Netherlands. The contents of the cases and the instructional approaches are explained in detail below. The subject related learning objectives are presented in Table 2 and CT-related learning objectives are shown in Table 3. CT related objectives are classified based on Selby's definition of CT (2015). Notably, the generalization skill is intentionally excluded from this study due to its incompatibility with the study's scope and nature.

**Case 1**. Unplugged decision tree (Augmentation): In a biology lesson, 9th grade students (age 13–16) learned the basic structure of a cell and the various types of cells. They had already discussed this topic in the previous lesson. First the teacher summarized the topic by direct instruction then he asked students to draw a decision tree to determine the types of cells (bacteria, fungi, plants, and animals) in as few steps as possible. Students drew their decision trees on paper individually. Each internal node in a decision tree represents a decision point based on a specific condition. Scaffolding was implemented by the teacher to give support to students whenever needed. As a part of collaborative learning, students had their decision tree checked by a classmate. They evaluated their classmate's decision tree according to predefined criteria (content, classification, and presentation/visualization). Then, they used the feedback obtained to create a second version of their decision tree. This lesson plan is categorized at the augmentation level, where CT concepts bring functional improvement without the necessity of digital or programming tools. The lesson is planned to contribute to the strengthening of reasoning skills within the biology context through the design of simple algorithms in the form of decision trees.

**Case 2**. Modelling - Modify (Modification): In physics lessons, 8th grade students (age 12–14) learned about the stopping distance of a moving vehicle which depends on the road conditions and the reaction speed of the driver. The first lesson was dedicated to theory. In the subsequent two lessons, the students used a simple model in Scratch provided by their teacher and researchers to explore the influence of icy

**Table 2**
Subject related learning objectives.

| | Lessons | | Learning Objectives | |
|---|---|---|---|---|
| Case 1 | **Int. Level**<br>**Subject**<br>**Grade**<br>**Instr. App**<br>**Duration** | Augmentation<br>Biology<br>9th<br>Unplugged decision tree<br>1 lesson | **Topic**<br>**Objectives** | *Cell type classification*<br>- Identify different types of cells.<br>- Describe the characteristics of each type of cell.<br>- Use the cell type knowledge to create a decision tree |
| Case 2 | **Int. Level**<br>**Subject**<br>**Grade**<br>**Instr. App**<br>**Duration** | Modification<br>Physics<br>8th<br>Modelling – Modify<br>3 lessons | **Topic**<br>**Objectives** | *Stopping distance*<br>- Describe the effects of a person's reaction time on the motion of objects.<br>- Notice stop distance can be affected by a range of factors (car, driver, road, and other conditions).<br>- Use the knowledge of factors that affect stop distance to modify the model |
| Case 3 | **Int. Level**<br>**Subject**<br>**Grade**<br>**Instr. App**<br>**Duration** | Redefinition<br>Biology<br>5th<br>Modelling-Create<br>4 lessons | **Topic**<br>**Objectives** | *Cell division*<br>- Recall functions of the cell and its organelles.<br>- Explain cell division following the steps in mitosis and meiosis.<br>- Illustr ate understanding of the two cell divisions by modelling |
| Case 4 | **Int. Level**<br>**Subject**<br>**Grade**<br>**Instr. App**<br>**Duration** | Redefinition<br>Language<br>8th<br>Storytelling<br>7 lessons | **Topic**<br>**Objectives** | *English Story Writing*<br>- Create a story by applying the Freytag pyramid.<br>- Include foreshadowing element into the story.<br>- Apply acquired English grammar & vocabulary.<br>- Use the correct pronunciation of the words. |

**Table 1**
The overview of four case studies.

| Case | School | Grade | Subject | Topic | CT Int Levels (SAMR) | CT Instructional Practices | Tools | Total # of Students | No Permission | Data Analysed |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | School 1 | SS | Biology | Cell type classification | Aug | Unplugged | Decision tree | 22 | 4 | 18 |
| **2** | School 1 | SS | Physics | Stop distance | Mod | Modelling | Scratch | 16 | 0 | 16 |
| **3** | School 2 | PS | Biology | Cell division | Red | Modelling | Scratch | 24 | 4 | 20 |
| **4** | School 3 | SS | English | Story with Freytag pyramid | Red | Storytelling | Scratch | 29 | 5 | 24 |

SS: Secondary school; PS: Primary School; Aug: Augmentation; Mod: Modification; Red: Redefinition.

**Table 3**
CT related learning objectives (Selby, 2015, pp. 80–87).

| Categories | C1. Unplugged Decision tree | C2. Modelling Modify | C3. Modelling Create | C4. Storytelling |
|---|---|---|---|---|
| ***Abstraction*** | | | | |
| Create visuals to represent data at an abstract level | Draw decision tree | Make visual changes on the model | Create digital visuals for model | Draw a storyboard and create digital visuals |
| Separate the important from the redundant information | Define relevant features that are most informative in making decisions. | Define essential parts of the model that require changes. | Define the key features that need to be represented in the model. | Define the key elements/themes that need to be represented in the story. |
| ***Algorithmic thinking*** | | | | |
| Design/Implement simple algorithms | Branching by using if conditions and data. Design step-by-step procedures. | Implement step-by-step procedures to achieve modifications in the model. | Implement step-by-step procedures to construct a new model. | Implement step-by-step procedures to construct a new digital story. |
| ***Decomposition*** | | | | |
| Divide a larger and more complex task into sub-tasks | Identify each node of the tree which represents a sub-task. | Modify the specific attributes without affecting the entire model. | Identify the different components of the model that need to be created. | Identify the different elements of the digital storytelling, such as scripting, creating visuals, recording audio, coding. |
| ***Evaluation*** | | | | |
| Evaluate the quality of solutions and identify improvements | Evaluate the effectiveness of decision tree, considering factors such as content, visuals, classification. | Evaluate the effectiveness of modifications on the model. | Evaluate the effectiveness of overall model, considering factors such as codes, functionality, and accuracy of content. | Evaluate the effectiveness of digital story; considering factors such as content, coherence, codes, visuals. |

road, and distractions on the stopping distance. Additionally, the students were asked to adjust the model's program code. This lesson is categorized at the modification level because the integration of CT concepts and related technology is planned to result in a transformative change in the learning outcomes. The modification involves students directly adjusting the model's program code, cultivating not only physics knowledge but also essential CT skills for a more comprehensive programming experience.

**Case 3**. Modelling - Create (Redefinition): In biology lessons, 5th grade students (age 10–11) learned about cells, what cells are, what cells look like, and how cell division works. In the first two lessons, the students learned about the concepts and about looking at cells with the use of a microscope. In the third and fourth lessons, the students created a model of cell division in Scratch. This lesson is classified at redefinition level because it allows students to not only grasp theoretical concepts but also actively engage in the creation of digital models, for implementing abstract ideas in the real digital solution for the context of biology.

**Case 4**. Storytelling (Redefinition): In language lesson, 8th grade students (age 12–15) learn to write English stories by using Freytag's pyramid, a framework to structure a story. In total, the lesson series continued for seven weeks, and each lesson was held for 1 h per week. In the first two lessons, the teacher gave an explanation about the requirements of the project. The teacher also showed a video explaining the different parts of a plot and Freytag's pyramid, and another video about the foreshadowing element. The next four lessons involved the implementation phase: students wrote their stories by using storyboards on paper and then converted it to a digital environment by coding in Scratch. In the last lesson, each group of students presented their digital story in the conference room. This lesson is categorized at the redefinition level because it requires more than theoretical comprehension, students need to implement a practical solution. The transition from traditional story-writing methods on paper with storyboards to an innovative digital environment, incorporating coding skills in Scratch, exemplifies a transformative learning experience.

### *3.3. Participants*

This study focusses on four different case studies encompassing a sample from one primary school and two secondary schools. Two cases were carried out at the same school (Unplugged and Modelling-Mod). Specifically, the sample consisted of 20 primary school students and 58 secondary school students. The primary school students' age range is between 10 and 11, with an average of 10. The secondary school students' age range is between 12 and 16, with an average of 13. The participants were 35 girls and 42 boys; one participant reported the gender as other (Table 4).

Students were also asked about their programming experience (Table 5). At School 1, where the Case 1(Unplugged) and Case 2 (Modelling-Mod) cases took place, nearly half of the students (14) had never any programming lessons. Out of the remaining 18 students, 12 had received programming lesson for less than one month, with four among them had lessons less than a year. Only two students had programming lessons for a period of 2–3 years. Case 3 (Modelling-red) and Case 4 (Storytelling) were implemented respectively at School 2 and 3, where all students had programming lessons previously. Students in Case 3 reported had programming lessons for 2–3 years. Additionally, students were surveyed about their programming experience, providing self-ratings on a scale from one (no experience) to five (very experienced). In Case 1 and Case 2, students rated their programming experience as an average of 2.3 and 2.4, respectively, while students in Case 3 and Case 4 rated themselves as 3.4 and 2.8.

### *3.4. Data collection and analyses*

A multi-method approach was employed to gather data, including demographic surveys, end-products/artifacts, exit tickets and open questions, student interviews. This diversified approach aimed to employ triangulation, enhancing the reliability of the research findings by cross-validating information obtained from multiple sources. Triangulation, through the collection of insights from distinct data collection methods, contributes to a more comprehensive and reliable understanding of the actual behaviors of students.

*Demographic Surveys:* At the beginning of the lesson series, all students filled in a demographic survey to provide contextual information such as age, gender, grade, access to technology, programming background/experience, self-efficacy related to programming.

*End products/Artifacts:* Various artifacts were collected across the case studies, including decision trees (Case 1), digital models (Cases 2 and 3), and storyboards and digital stories (Case 4). Decision trees and storyboards were collected as hard copies, while digital models and stories were submitted via Scratch project links.

*Exit tickets and Open questions:* At the end of the lesson series, students completed exit tickets using a three-point Likert scale and responded to

**Table 4**
Demographic information of participants.

| Cases | CT Instructional Practices | CT Int. Lev | School type | Age range | Aver. Age | Gender | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | F | M | Don't mention |
| 1 | Unplugged | Aug | Secondary | 13–16 | 14 | 9 | 8 | 1 |
| 2 | Modelling | Mod | Secondary | 12–14 | 13 | 9 | 7 | 0 |
| 3 | Modelling | Red | Primary | 10–11 | 10 | 9 | 11 | 0 |
| 4 | Storytelling | Red | Secondary | 12–15 | 13 | 8 | 16 | 0 |
| | | | | | **Total** | **35** | **42** | **1** |

**Table 5**
Prior experience of participants.

| | | | Programming Lesson | | | Programming Lesson Duration | | | | Programming Experience |
|---|---|---|---|---|---|---|---|---|---|---|
| Cases | CT Instructional Practices | CT Int. Lev | Yes | No | Learn by myself | <1 month | 1 m to 1 year | 2–3 years | >3 years | 1 (No exp.) to 5 (Very exp.) |
| 1 | Unplugged | Aug | 11 | 6 | 1 | 6 | 3 | 1 | 0 | 2,3 |
| 2 | Modelling | Mod | 8 | 7 | 1 | 6 | 1 | 1 | 1 | 2,4 |
| 3 | Modelling | Red | 20 | 0 | 0 | 2 | 0 | 18 | 0 | 3,4 |
| 4 | Storytelling | Red | 24 | 0 | 0 | 1 | 21 | 2 | 0 | 2,8 |

open-ended questions. The purpose of the exit tickets and open questions is to form a picture about the views of the students related to their end products and the CT integrated lessons. Therefore, we used the following indicators: perceived usefulness, attitude, perceived difficulties, and behavioural intention about CT integrated lessons. For the exit ticket statements, students could choose for each statement with "yes, unsure, or no", while students could provide a broad and in-depth opinion with open questions.

*Student Interviews:* At the end of the lesson series, interviews were conducted with a subset of students individually. In each case study, interviews were conducted with a different number of students, respectively as follows: with four students in the Case 1 with three students in the Case 2, with two students in the Case 3. Only for the Case 4, we conducted focus group interviews with four groups of students (in total 12 students). The variation in interview styles across case studies was done intentionally because of the unique characteristics of each case. In Case 4, lessons continued for seven weeks, and students collaborated for a longer period compared to other cases. A focus group setting allowed us to capture students' experiences and the collaborative nature of the lessons. Participants for interviews were selected based on their engagement with the CT-integrated lessons and their representation across different case studies. Efforts were made to include a diverse sample in terms of programming experience and demographic background. In all cases, we followed a semi-structured interview protocol that included questions regarding students' end products, the CT-integrated lessons, collaboration, and CT integration with other subjects. Students' in-depth experiences and opinions were obtained through these interviews. Interviews lasted approximately 10 min on average. Focus group interviews in Case 4 lasted about 15 min to accommodate group interactions and collaborative discussions.

*Analysis:* The interviews were transcribed using a standard verbatim approach. Pseudonyms were used in the transcripts, and personal pronouns have been converted to gender-neutral pronouns (they/them/their). The interview data were analysed deductively by the first author, resulting in the identification of four themes aligned with the TAM model: (1) Perceived usefulness of lessons, (2) Perceived ease of use (how to deal with difficulties), (3) Attitude (enjoy, like least, like most, satisfaction with lessons, satisfaction with artifacts), (4) Behavioural intention for future. To ensure coding reliability, a subset of transcripts was independently coded by a second researcher, and any discrepancies were resolved through discussion. This validation process helped ensure the robustness of the thematic analysis.

The exit tickets were analysed using the SPSS, version 27. Mean, SD, range, and internal consistency (Cronbach's alpha) were calculated for each subgroup. TAM components were explored for students from each different case study, and they were compared between each other.

## 4. Results

### 4.1. Perceived usefulness

The perceived usefulness of the technology acceptance model (TAM) can explain how students form beliefs and thoughts about the usefulness of CT integration practices and how these practices help them to learn the topic better and whether they understand the material. We asked these questions to all students with practice assignments (open questions) and exit tickets, we also discussed them in-depth during the interviews. Two items formed the subgroup of perceived usefulness. Scores ranged between 1 (Disagree) and 3 (Agree), $M = 1.99$, $SD = 0.97$. Internal consistency of the subgroup was acceptable, $\alpha = 0.61$. Modelling-create case students scored the highest on the factor that the CT integrated lessons helped to learn the subject better ($M = 2.50$, $SD = 0.82$). Storytelling students scored lowest compared to other cases students in terms of help to understand topic better ($M = 1.42$, $SD = 0.83$). The perceived usefulness for all cases is listed in Table 6.

*C1- Unplugged Decision Tree:* Based on open questions, most of the students (12 out of 18) told that the decision tree activity helped them to understand the cell determination topic better, because they said, "you see the overview … you ask yourself questions and answer them yourself." "I can do better identification now, it doesn't only help with science, but you can do that with everything". Additionally, based on the exit ticket questions, almost all students (16) said that they understood the lesson material well.

*C2- Modelling-Modify:* Based on open questions, more than half of the students (9 out of 17) told that modifying the model does not help them

**Table 6**
Perceived usefulness toward CT integration practices.

| | | N | Mean | SD |
|---|---|---|---|---|
| Help to understand topic better | C1- unplugged decision tree | 18 | 2.39 | 0.91 |
| | C2- modelling modify | 16 | 1.75 | 0.93 |
| | C3- modelling create | 20 | 2.50 | 0.82 |
| | C4- storytelling | 24 | 1.42 | 0.83 |
| | **Total** | **78** | **1.99** | **0.97** |
| Understand the lesson material | C1- unplugged decision tree | 18 | 2.89 | 0.32 |
| | C2- modelling modify | 16 | 2.63 | 0.61 |
| | C3- modelling create | 20 | 2.75 | 0.44 |
| | C4- storytelling | 24 | 1.79 | 0.88 |
| | **Total** | **78** | **2.46** | **0.76** |

to understand the stopping distance topic better. One student clarified that it is very different from a school subject. During the interviews, one of the five students expressed that they learned it in a fun way which helps to remember it better. One student explained that this model with formulas might also help to learn other subjects such as math. Almost all students (11) students said that they understood the lesson material well.

*C3- Modelling-Create:* Based on open questions, most of the students (14 out of 24) told that these lessons helped them to understand the cell division topic better. One student said that it is more fun to learn, another student explained that they must do it themselves and then they can understand it better. One of the interviewed students indicates that they can learn better if they like the lesson and that they therefore understand cell division better now.

*C4 – Storytelling:* Based on open questions, most of students (19 out of 24) told that the digital storytelling activity does not help them to learn English better. As a reason, four of them told that "No, I was already pretty good at English, but I trained." Only a few of them (5) told that they must speak during lessons, and they have learned new words. During the interviews some students told that "While writing the script and storyboard, we were able to practice English", another student added "Pronunciation can still go wrong sometimes, so that's kind of something new to learn because we have a project that we have to speak for very occasionally, but almost never actually." Also, they think that this activity is good for the collaboration, they like to work together, and they learn from each other. 12 of students said that they don't understand the material well.

### 4.2. Perceived ease of use

The perceived ease of use indicates whether students find the CT integration practices difficult, what students find most difficult, and how they deal with these difficulties. We asked these questions to all students with practice assignments (open questions) and exit tickets, and we also discussed them in-depth during the interviews. One item formed the subgroup of the perceived ease of use. Scores ranged between 1 (Disagree) and 3 (Agree), $M = 2.35$, $SD = 0.66$. Unplugged decision tree students scored the highest in the factor that they find the lesson easy, compared to students who worked on the other cases ($M = 2.44$, $SD = 0.70$). Perceived ease of use for all cases is listed in Table 7.

*C1- Unplugged Decision Tree:* Based on open questions, more than half of students (10) found everything very easy. Only two students found the lessons difficult while six students stated that they were unsure on this issue. During the interviews, a student stated that "I like this decision tree activity because it was easy!".

*C2- Modelling-Modify:* Based on open questions, almost half of students (7) agreed that the most difficult part is programming and the game making part. During the interviews, one student told that when they had a problem with the coding part, they asked help to the teacher, and it was solved by this way.

*C3- Modelling-Create:* Based on open questions, the factors that students found difficult varied: some students (6) found coding difficult, some students (6) had difficulties with cell division, and some students (4) found thought processes (inventing, thinking, keep focusing etc.) difficult. During the interviews, a student who had difficulty with coding told that they solved the problem by asking help to the teacher.

**Table 7**
Perceived ease of use toward CT integration practices.

| | | N | Mean | SD |
|---|---|---|---|---|
| Find the lesson easy | C1- unplugged decision tree | 18 | 2.44 | 0.70 |
| | C2- modelling modify | 16 | 2.19 | 0.75 |
| | C3- modelling create | 20 | 2.35 | 0.48 |
| | C4- storytelling | 24 | 2.38 | 0.71 |
| | **Total** | **78** | **2.35** | **0.66** |

*C4 – Storytelling:* Based on open questions, 9 children stated that they had the most difficulty in the programming part of the project. Other difficulties a forenamed by students are communication, allocation of roles (task sharing), writing the script of the story, time scheduling. An interviewed student mentioned that "it is difficult to come up with a story." Another student told that "[related to the programming part] I'm having a lot of trouble … [to deal with it] we discussed well with each other, and division of labour really helped." Another student told that "I found programming difficult, but it was fun to learn it" Also, one of the students who had problems with scheduling, clarified that "[…] maybe next time it would be nice if you make us a schedule that we can stick to, so that it all goes a bit smoother." Some students had technical problems (such as changing audio format or forgetting to save) and they learned to deal with these problems by themselves.

### 4.3. Attitude toward lessons

Students' attitude indicates how students feel about CT integration practices and end products including enjoyment, satisfaction, interest, and preferences (likes/dislikes). We asked these questions to all students with practice assignments (open questions) and exit tickets, we also discussed them in-depth during the interviews. Two items formed the subgroup "perceived usefulness". Scores ranged between 1 (Disagree) and 3 (Agree), $M = 2.47$, $SD = 0.50$. Internal consistency of the subgroup was good, $\alpha = 0.806$. Modelling-create case students scored the highest on the factor that they enjoyed the lesson and found the lesson interesting ($M = 2.90$, $SD = 0.30$). Unplugged decision tree case students scored lowest compared to students of the other cases in terms of enjoyment factor ($M = 2.17$, $SD = 0.78$). Attitudes of students for all cases are listed in Table 8.

*C1- Unplugged Decision Tree:* Based on open questions, all the students (18) have been satisfied with their decision trees which they made to determine different cell types. One student stated that they were satisfied because it helps to learn better. The students' favourite parts of the lesson were drawing a decision tree (6) and working together (2). During the interview a student told that "I like it because it was easy." And another student said that they are happy with the decision tree because they can find anything [about cell types] just by looking at it. Based on the exit ticket questions, for the enjoyment aspect, less than half of students (7) stated that they enjoyed the lesson.

*C2- Modelling-Modify:* Based on open questions, almost all students (14) were satisfied with the animation related to stop distance. One of students stated that "I'm glad I changed a lot […] Less happy that I couldn't make my own game". Many students (9) found the best part of the lesson as "programming part (or editing code/making game)". For two students, the best part is "collaboration (working together)". Six students stated that the least interesting part of the lesson is the theoretical part where they have to listen and watch an animation (film). During the interviews, students explained that what kind of changes they made during the lesson, they said that they changed the car or the object which affected stop distance (for example they changed phone with snowman etc.). Related to the changes, one student said that "I

**Table 8**
Attitudes of students toward CT integration practices.

| | | N | Mean | SD |
|---|---|---|---|---|
| Enjoyment in the lesson | C1- unplugged decision tree | 18 | 2.17 | 0.78 |
| | C2- modelling modify | 16 | 2.25 | 0.85 |
| | C3- modelling create | 20 | 2.90 | 0.30 |
| | C4- storytelling | 24 | 2.50 | 0.72 |
| | **Total** | **78** | **2.47** | **0.73** |
| Find the lesson interesting | C1- unplugged decision tree | 18 | 2.44 | 0.70 |
| | C2- modelling modify | 16 | 2.19 | 0.75 |
| | C3- modelling create | 20 | 2.90 | 0.30 |
| | C4- storytelling | 24 | 2.29 | 0.69 |
| | **Total** | **78** | **2.46** | **0.67** |

made the changes because it just looks nice". Another student said that they liked that better than if they just started with nothing instead of change or expand an existing project. Because they added it is fun to find out how it works, and they can learn it too.

*C3- Modelling-Create:* Based on open questions, more than half of students (12) were satisfied with their cell-division animation which they created themselves. Only four students who are dissatisfied with their animation, two of them told that "I'm happy that we were able to clone cells, but I'm not happy that the clones couldn't move." Another student said that "We wished for more cell types." The best part of the lesson is "Programming/Scratch" for many students (11). Secondly, they (7) liked most to observe cells with the microscope. On the other hand, six students who liked programming the most, stated that the least favourite part of the lesson is to observe cells with a microscope. And one student said that they liked to work together with their friend. One student said that they did not like to wait for help.

During the interviews, related to satisfaction with their models, a student told that "I would like to make more cells and that they all move too." According to a student, the best part of the lesson is to be able to **come up with a final product**, a student told that "I like the fact that they just keep cloning all the time and then you end up seeing the whole picture like this. And yes, that we figured out how to put this together ourselves." and also added that they learned better in this way compared to learning from books.

*C4 – Storytelling:* Based on open questions, the great majority of students (19) are satisfied with their stories, some students think their stories are creative, while others think their stories meet all the requirements. Those who are dissatisfied with their story have different reasons, such as not being able to deliver their projects on time, thinking that the programming part could be better, finding their story short, dissatisfied with the task of the other group member, etc.

Many students (14) liked most to **create/produce a new thing** and they expressed their favourite thing about the lesson as follows: "in a short time make an advanced project", "create/make up the story/script", "make images", "the end result", "making a scratch", "computer programming", "speaking", "freedom in creativity". Two students elaborated it as "[…] except that you had to have interaction and a certain structure, you had complete freedom in which direction you wanted to go with your story", "it was fun because we had a lot of freedom". Secondly, some students (7) liked the most about the lesson was **collaboration**, and they expressed it in different ways: "brainstorm together", "interaction with classmates", "work together". While 8 students stated that the part of the lesson, they disliked most was programming/coding, however, 3 students did not like to write the scenario of the story. During interviews a student told that "I found it interesting to learn in a different way." A student gave a tip about media/tool such as: "[…] maybe we could work in **another program easier than Scratch**, […] because we also worked with Python first […] We really found Python a bit more convenient than Scratch, because every time we went to save, Scratch would say it was not saved and to try again. So, we kind of double-worked, and if it hadn't been for that, maybe we could have worked out the script longer". Another student also added that they **could not be creative enough in the Scratch** environment, "Sometimes scratch didn't quite cooperate, we couldn't do exactly what we wanted". About **clear instructions/scaffolding** a student satisfied with that and explained: "The lessons went well because you [C4 teacher and first author] explained well, and everything was understandable. We knew exactly what to do, it doesn't get unclear, but it was up to us whether we went to work or not."

### 4.4. Behavioural intention

The behavioural intention component can explain students' behavioural intentions and whether they want to be involved in these types of lessons/projects in the future. Students were also asked whether they could associate such learning approaches with other courses. We asked these questions to all students with practice assignments (open questions) and exit tickets, we also discussed them in-depth during the interviews. One item formed the subgroup "behavioural intention". Scores ranged between 1 (Disagree) and 3 (Agree), M = 1.92, SD = 0.96. Modelling-create case students scored the highest on the factor that they want to be involved in this type of lessons in the future (M = 2.70, SD = 0.73). Storytelling students scored lowest compared to students from other cases in terms of future intention (M = 1.46, SD = 0.78). Students' behavioural intention for all cases is listed in Table 9.

*C1- Unplugged Decision Tree:* Majority of the students (11) do not want to make decision trees again to help them learning in school subjects. During the interviews, a student stated that "No [don't want to do it again], unless it's a really hard topic", while another student added that "I think it's a lot of work to do". This might be since there are students in this case with diverse academic skills and they progress through various educational tracks (basic/pre-vocational/theoretical pathway/higher general continued education/pre-university education). On the other hand, five students stated that they want to make decision trees for other subjects/topics (e.g., "animals").

*C2- Modelling-Modify:* Half of all students (8) do not want to modify a model again to learn a school subject. As a reason, a student said that "**programming and stuff like that isn't for me**", another student said that "no, because it is **very different from a school subject**". On the other hand, other half of students (7) said that they want to do that for other subjects such as English, math, music, or technology lessons. Different students added that "I remember it better and it's more fun!", "it is useful", "it would be nice to do it again." During interviews, related to math integration a student said that "In math there are plenty of formulas and if you change something in that [Scratch model], you can see it immediately, it will help you". Furthermore, a student told that "if you learn it in a fun way, it just sticks better with me, then I remember". Another student who found coding part funny said "It's funny, especially that you learn coding and stuff. Yes [liked it], because it doesn't really happen much at school, I think that's a shame […] Because it's fun and we're getting more and more into computers and stuff. And I think there are also some shortcomings [developers and stuff]. I like it too. I also want to do it later [as a career]." The same student added that "Yes [would like to see it at school more often], and then later in the years a bit more difficult, that you actually use C++ and stuff … I think they're [other students] going to get a bit stuck, but then I mean you do that more and more until they understand."

*C3- Modelling-Create:* Almost all students (17) want to make a model again to learn other school subjects such as mathematic (calculation, tables), spelling, language, computer programming, almost any subject (2). Only three students thought that it is not applicable to other subjects. During the interview a student told that "Yes [would like to use Scratch like this again]. Because I like this program, you can do a lot with it."

*C4 – Storytelling:* We asked students whether they like to make the digital story again to help with learning their school subjects. Most of the students (16) do not want to make digital stories for other subjects. One student added "it takes a lot of time". However, six students stated that it is applicable to other subjects such as other language lessons (French, Dutch, German), geography, history (remember better the numbers of years and what happened), math, art (design something such as game).

**Table 9**
Behavioural intentions of students toward CT integration practices.

| | | N | Mean | SD |
|---|---|---|---|---|
| Want to be involved in this type of lessons in the future | C1- unplugged decision tree | 18 | 1.67 | 0.91 |
| | C2- modelling modify | 16 | 1.94 | 0.99 |
| | C3- modelling create | 20 | 2.70 | 0.73 |
| | C4- storytelling | 24 | 1.46 | 0.78 |
| | **Total** | **78** | **1.92** | **0.96** |

Students stated that “The student is also equally motivated and more active than working from the book”, “yes we can do that but for example once in a year or so.” During the interviews, a student told that “I would like to do that again, if we have enough time, because it takes a lot of time.” Related to student’s intention for the integration to other subjects, a student told that “[…] with Scratch it is really a lot of extra work that you can just as well do it on paper.”

## 5. Conclusion and discussion

The current study has illuminated the significant impact of different CT integration practices, including Unplugged, Modelling (Modify and Create) and Storytelling methods. It has examined their effects in subject learning, revealing their effectiveness in shaping students’ perceived usefulness, ease of use, attitudes towards the courses, and their future behavioural intentions. Independently of the instructional strategies employed, it is evident that various factors influence students’ behavioural intentions, such as their programming backgrounds and individual characteristics like age and gender (Chow et al., 2012; Davis, 1989). Notably, our findings suggest that primary school students with prior programming experience, such as in the modelling-creation case, display a higher behavioural intention due to a lack of early biases toward programming. These results are consistent with the idea that early exposure to computer science can foster a more positive outlook on the subject (Bers et al., 2014; Hamilton, Clarke-Midura, Shumway, & Lee, 2019).

Another finding indicates that students’ perceived usefulness is notably high in the modelling-create and unplugged cases. In these cases, students indicated that CT integrated lessons helped them learn the subject better. On the other hand, in the context of perceived usefulness, it is noteworthy that the modelling-create case received the highest rating, while the storytelling activities were rated the lowest. It is interesting to observe that even though both cases have been categorized at the redefinition level (to create a digital solution for the subject problem), the highest level of CT integration, the utilization of extensive programming or advanced technologies is not consistently deemed beneficial by students. While the redefinition level of CT integration encourages a transformative approach to lessons, it is evident that the mere presence of advanced technology or programming does not guarantee improved subject related learning experiences. It draws the attention to the importance of how the technologies/programming used contribute to the learning of the subject matter. It prompts educators and curriculum designers to consider not only the level of CT integration but also the context, purpose, and appropriateness of the technologies employed. The goal is to harness technology to deepen and enhance the learning of subject matter, fostering a more meaningful and effective educational experience (Koehler et al., 2011).

Additionally, the unplugged case consisting of the decision tree activity is an example of the augmentation level of CT integration (lower level) and it stands out as the most user-friendly, with students finding it the easiest to use. It is noteworthy that nearly all students reported a clear understanding of the lesson material in this context. Furthermore, the user-friendliness of this unplugged case underscores the importance of ensuring that educational experiences are accessible and comprehensible to students. As educators and curriculum designers, prioritizing user-friendly unplugged approaches can lead to enhanced engagement, satisfaction, and ultimately, improved learning outcomes for students (Bell & Lodi, 2019; Brackmann et al., 2017).

Our results may also contribute to the debate regarding whether CS should be taught as a separate standalone subject (multidisciplinary approach) or integrated into other subjects within the curriculum (interdisciplinary approach). In a multidisciplinary approach, the learning objectives of each course are taught within themselves. For example, while programming concepts are taught in the CS course, the subject of cell division is among the teaching objectives of the science course. The course contents and teaching approaches suggested in the current study are products of an interdisciplinary approach. In other words, it has been developed by using the approaches and teaching objectives of different disciplines in the same course, where the boundaries of different disciplines have disappeared. For example, science and CS approaches were used together in the activity of modelling cell division. Teaching CS as a distinct discipline equips students with a comprehensive understanding of programming, algorithms, and problem-solving techniques (Wing, 2006). Simultaneously, educators are exploring ways to integrate CT skills into existing disciplines, promoting the application of these skills to tackle complex problems (Yadav et al., 2016). This study is based on a noteworthy aspect of the current educational landscape — the shift from a multidisciplinary approach toward an interdisciplinary approach. However, in the current education system, students and teachers are not very accustomed to an interdisciplinary approach (Karppinen et al., 2013; Yeni et al., 2023). This is also apparent in the statement of a student, in the modelling-modify case, where the student said "[…] **it is very different from a school subject** ". It is observed in this study that this interdisciplinary approach has the potential to expand students’ horizons but may initially lead to less positive results regarding their future intentions since they are not very familiar with these types of interdisciplinary lessons. Our study highlights this transition as a factor that requires further exploration.

The results of our study reveal shared preferences among students across all the distinct case studies. Many students like most to **create new products** (a story/end product/picture/code/model/decision tree etc.). Students expressed themselves in their end products and they infused their interests and personal styles into their artifacts. In the context of integrating CT into various subject areas, it is essential to recognize that programming goes beyond mere code writing; it becomes a means of self-expression and creativity (Kafai et al., 2019, pp. 101–109). This perspective aligns with Tsortanidou et al.’s (2019) pedagogical model, which strives to connect creativity with CT and new media literacy skills. This innovative model emphasizes that the combination of CT, collaboration, and creativity leads students to holistic development, engaging them in think, feel, and do. Secondly, for all case studies, students like most to **collaborate with other students**. Students frequently stated that they like to work together and that cooperating allows them to learn from each other. It is observed that students from diverse skill sets collaborated, and they brought varied perspectives, it helped them to come up with more effective solutions. Aligning with this perspective, Kafai et al. (2019, pp. 101–109) emphasized the concept of “situated CT”, which highlights the significance of personal creative expression and social engagement as a pathway to computational fluency. This approach builds upon the inherent interest that students have in digital media and production (Kafai et al., 2019, pp. 101–109). Teachers might help students to develop CT skills by encouraging them to express themselves creatively and engage socially in the digital space.

According to observation of researchers, implementing CT across different subjects involves navigating various **logistical and pedagogical challenges**. These include aligning CT activities with existing curricula, ensuring adequate technological resources, and addressing diverse student needs. Schools must consider how to integrate CT without overwhelming existing lesson plans or compromising other essential learning objectives. The study underscores that the effectiveness of CT integration is not solely dependent on the level of technology used but also on how well these tools are integrated into the educational context.

Effective integration of CT into the classroom is heavily influenced by **teacher preparedness**. The study indicates that teachers often face barriers such as limited computer science training and insufficient professional development opportunities. Addressing these issues is essential for successful implementation. Teachers require targeted training to develop a deep understanding of CT concepts and to effectively incorporate these into their teaching practices. Professional development should focus on equipping educators with both the technical skills and pedagogical strategies necessary for integrating CT into various subjects. It should be considered that the study's design and convenience sampling limit generalizability, as participants came from a specific group of schools. Future research should explore diverse instructional models and integration strategies for a broader understanding of CT integration.

### 5.1. Implication suggestions

Our findings on CT integration practices may also provide insights into the potential design principles of CT integrated interdisciplinary lessons (see also, Nijenhuis-Voogt et al., 2022; Yeni et al., 2022, 2023):

- ***Contextualized Interdisciplinary Approach:*** The study found that CT integration was more effective when lessons were designed with a clear and cohesive storyline that aligned with both the subject matter and computational principles. Lessons should be tailored to bridge the gap between computing and disciplinary content, as evidenced by the enhanced student engagement and understanding observed in our case studies.
- ***Enhanced Co-design Process:*** Our research highlighted that the co-design process, involving collaboration between teachers and researchers, significantly improved the implementation of CT lessons. This approach helped address the challenges teachers face, such as limited CS training and support. Future implementations should incorporate similar co-design practices to ensure that teachers are well-equipped and confident in integrating CT.
- ***Focused Learning Objectives:*** The study demonstrated that having clearly defined learning objectives is important for CT integration practices (Table 3). This specificity allowed students to understand the goals and expected outcomes of their CT activities, enhancing their learning experience.
- ***CT Integration Levels:*** Findings indicate that varying levels of CT integration, from augmentation to redefinition, impact student perceptions differently. For example, while high-tech methods like modeling and storytelling were engaging, their perceived usefulness varied. It is important to match the level of CT integration with the context and purpose of the lesson to optimize its impact (Yeni et al., 2023- ).
- ***Student-Centred and Collaborative Learning:*** It revealed that student-centred and collaborative approaches were particularly effective in fostering engagement and creativity. By allowing students to take ownership of their projects and work together, lessons became more enjoyable and students create meaningful artifacts. Students liked most to be creative and work together. Situated CT highlights the significance of personal creative expression and social engagement (Kafai et al., 2019, pp. 101–109).
- ***Adaptive Teaching Methods:*** Adaptation of teaching methods based on students' and teachers' prior knowledge and needs proved effective in our study. Different grade levels and subjects may require varying approaches to CT integration. For example, a storytelling activity that requires coding for students who are experienced in programming is considered to address diverse students' needs.

In addition to these potential design principles of four different CT integration lessons, further investigation into design principles can provide valuable insights into optimizing CT integration into curriculum. As the field continues to evolve, it is essential to adapt teaching approaches to better prepare teachers and students for the digital world and equip them with the problem-solving and computational skills they need to excel in their academic and professional journeys (Sands et al., 2018).

## CRediT authorship contribution statement

**Jacqueline Nijenhuis-Voogt:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Mara Saeli:** Writing – review & editing, Supervision, Conceptualization. **Erik Barendsen:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Felienne Hermans:** Writing – review & editing, Supervision, Project administration.

## Limitations

This study provides valuable insights into the integration of computational thinking (CT) in upper primary and lower secondary education. However, due to the nature of cross-case studies, it is difficult to generalize findings beyond the specific cases examined. Further research could explore the effect of interdisciplinary CT integration on students' learning/views with a quantitative or mixed study on a larger scale. In addition, the current study may not capture long-term effects or changes in instructional practices. The lessons' duration has been limited (one, two, four or eight lessons), which could impact the ability to observe how the integration of CT evolves over time.

Related to data analysis procedure, we used The Technology Acceptance Model (Davis, 1989), which is a widely used framework for understanding how individuals accept and adopt new technologies/tools/practices. In our study, TAM provided valuable insights into students' adoption of CT integration, but it also has its limitations. There might be some measurement challenges, since TAM relies on self-reported measures of perceived ease of use and perceived usefulness, which can be response biases. To avoid this and to ensure data triangulation, we chose to use different data collection sources together such as end products, interviews, exit tickets etc. Additionally, students may not always possess a well-defined understanding of the actual utility of such practices, or their understandings may change over time. This situation prompts critical reflections on the TAM, especially in its efficacy in predicting student perceptions regarding technology adoption. Also, making CT integration practices/tools useful and useable does not predict adoption; context plays a large role in adoption (Shreiner & Guzdial, 2022).

## Selection and participation of children

In this study, we made a collaboration with a few schools in the Netherlands. These schools are part of the Dutch School Collective Openbaar Onderwijs Groningen (O2G2) which is the partner of this research project. Several teachers at these schools have been granted time to develop and test new lesson programs and share the innovations with colleagues. In these schools, we had a total of 78 participants, 20 of them are from primary school students and 58 of them are from secondary schools within the Netherlands. Parents signed informed consent forms, which included a data collection policy and consent for audio/video to be recorded. All personally identifiable data was removed to protect the participants' anonymity.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Sabiha Yeni reports financial support was provided by The Netherlands Initiative for Education Research (NRO). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Data availability

The authors do not have permission to share data.

## References


Astrachan, O., Cuny, J., Stephenson, C., & Wilson, C. (2011). The CS10K project: Mobilizing the community to transform high school computing. *Proceedings of the 42Nd ACM technical symposium on computer science education* (pp. 85–86). https://doi.org/10.1145/1953163.1953193

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads, 2*(1), 48–54. https://doi.org/10.1145/1929887.1929905

Basu, S., Biswas, G., & Kinnebrew, J. S. (2017). Learner modeling for adaptive scaffolding in a Computational Thinking-based science learning environment. *User Modeling and User-Adapted Interaction, 27*(1), 5–53.

Bell, T., & Lodi, M. (2019). Keeping the "computation" in "computational thinking" through unplugged activities. *CONSTRUCTIVIST FOUNDATIONS, 14*(3), 357–359. SI.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education, 72*, 145–157.

Brackmann, C. P., Román-González, M., Robles, G., Moreno-León, J., Casali, A., & Barone, D. (2017). Development of computational thinking skills through unplugged activities in primary school. *WiPSCE*, 65–72.

Burke, Q., & Kafai, Y. B. (2010). Programming & storytelling: Opportunities for learning about coding & composition. *Proceedings of the 9th international conference on interaction design and children.* https://doi.org/10.1145/1810543.1810611

Burke, Q., & Kafai, Y. B. (2012). The writers' workshop for youth programmers: Digital storytelling with scratch in middle school classrooms. *Proceedings of the 43rd ACM technical symposium on computer science education*.

Caeli, E. N., & Yadav, A. (2020). Unplugged approaches to computational thinking: A historical perspective. *TechTrends, 64*(1), 29–36.

Cateté, V., Lytle, N., Dong, Y., Boulden, D., Akram, B., Houchins, J., Barnes, T., Wiebe, E. N., Lester, J. C., Mott, B. W., & Boyer, K. (2018). Infusing computational thinking into middle grade science classrooms: Lessons learned. *WiPSCE, 21*(1–21), 6.

Chen, H.-L., & Wu, C.-T. (2021). A digital role-playing game for learning: Effects on critical thinking and motivation. *Interactive Learning Environments*, 1–13. https://doi.org/10.1080/10494820.2021.1916765

Chow, M., Herold, D. K., Choo, T.-M., & Chan, K. (2012). Extending the technology acceptance model to explore the intention to use Second Life for enhancing healthcare education. *Computers & Education, 59*(4), 1136–1144. https://doi.org/10.1016/j.compedu.2012.05.011

Cuny, J., Snyder, L., & Wing, J. M. (2010). *Demystifying computational thinking for non-computer scientists. Work in Progress*.

Davis, F. D. (1985). *A technology acceptance model for empirically testing new end-user information systems: Theory and results [thesis*. Massachusetts Institute of Technology. https://dspace.mit.edu/handle/1721.1/15192.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://doi.org/10.2307/249008

Dong, Y., Cateté, V., Jocius, R., Lytle, N., Barnes, T., Albert, J., Joshi, D., Robinson, R., & Andrews, A. (2019). Prada: A practical model for integrating computational thinking in K-12 education. *SIGCSE*, 906–912.

Faber, H. H., Wierdsma, M. D., Doornbos, R. P., van der Ven, J. S., & Vette, K. de (2017). Teaching computational thinking to primary school students via unplugged programming lessons. *Journal of the European Teacher Education Network, 12*, 13–24.

Göbel, S., Salvatore, L., & Konrad, R. (2008). StoryTec: A digital storytelling platform for the authoring and experiencing of interactive and non-linear stories. *2008 international conference on automated solutions for cross media content and multi-channel distribution* (pp. 103–110). https://doi.org/10.1109/AXMEDIS.2008.45

Hamilton, M., Clarke-Midura, J., Shumway, J. F., & Lee, V. R. (2019). An emerging technology report on computational toys in early childhood. *Technology, Knowledge and Learning, 25*(1), 213–224. Learning Mathematics, Science and the Arts in the Context of Digital Technologies.

Holden, R. J., & Karsh, B.-T. (2010). The Technology Acceptance Model: Its past and its future in health care. *Journal of Biomedical Informatics, 43*(1), 159–172. https://doi.org/10.1016/j.jbi.2009.07.002

Hutchins, N., Biswas, G., Conlin, L., Emara, M., Grover, S., Basu, S., & McELHANEY, K. (2018). Studying synergistic learning of physics and computational thinking in a learning by modeling environment. *26th international conference on computers in education (ICCE), manila, Philippines*.

Jantsch, E. (1972). Inter- and transdisciplinary university: A systems approach to education and innovation. *Higher Education, 1*(1), 7–37. https://doi.org/10.1007/BF01956879

Kafai, Y., Proctor, C., & Lui, D. (2019). From theory bias to theory dialogue: Embracing cognitive, situated, and critical framings of computational thinking in K-12 CS education. *Proceedings of the 2019 ACM conference on international computing education research.* https://doi.org/10.1145/3291279.3339400

Kallia, M., van Borkulo, S. P., Drijvers, P., Barendsen, E., & Tolboom, J. (2021). Characterising computational thinking in mathematics education: A literature-informed delphi study. *Research in Mathematics Education, 23*(2), 159–187. https://doi.org/10.1080/14794802.2020.1852104

Karppinen, S., Kallunki, V., Kairavuori, S., Komulainen, K., & Sintonen, S. (2013). Interdisciplinary integration in teacher education. In *Interaction in educational domains* (pp. 147–158). Brill. https://brill.com/downloadpdf/book/edcoll/9789462093959/BP000013.pdf.

Kelleher, C., & Pausch, R. (2007). Using storytelling to motivate programming. *Communications of the ACM, 50*(7), 58–64.

Koehler, M. J., Mishra, P., Bouck, E. C., DeSchryver, M., Kereluik, K., Shin, T. S., & Wolf, L. G. (2011). Deep-play: Developing TPACK for 21st century teachers. *International Journal of Learning Technology, 6*(2), 146–163. https://www.inderscienceonline.com/doi/10.1504/IJLT.2011.042646.

Lee, I., Grover, S., Martin, F., Pillai, S., & Malyn-Smith, J. (2020). Computational thinking from a disciplinary perspective: Integrating computational thinking in K-12 science, technology, engineering, and mathematics education. *Journal of Science Education and Technology, 29*(1), 1–8. https://doi.org/10.1007/s10956-019-09803-w

Lee, I., Martin, F., Denner, J., Coulter, B., Allan, W., Erickson, J., Malyn-Smith, J., & Werner, L. (2011). Computational thinking for youth in practice. *ACM Inroads, 2*(1), 32–37. https://doi.org/10.1145/1929887.1929902

Louca, L. T., Zacharia, Z. C., Michael, M., & Constantinou, C. P. (2011). Objects, entities, behaviors, and interactions: A typology of student-constructed computer-based models of physical phenomena. *Journal of Educational Computing Research, 44*(2), 173–201.

Lytle, N., Cateté, V., Boulden, D., Dong, Y., Houchins, J., Milliken, A., Isvik, A., Bounajim, D., Wiebe, E. N., & Barnes, T. (2019). Use, modify, create: Comparing computational thinking lesson progressions for STEM classes. *ITiCSE*, 395–401.

Malyn-Smith, J., Lee, I. A., Martin, F., Grover, S., Evans, M. A., & Pillai, S. (2018). Developing a framework for computational thinking from a disciplinary perspective. *Conference proceedings of the international conference on computational thinking education*.

Marangunić, N., & Granić, A. (2015). Technology acceptance model: A literature review from 1986 to 2013. *Universal Access in the Information Society, 14*(1), 81–95. https://doi.org/10.1007/s10209-014-0348-1

Merriam, S. B. (2009). Qualitative case study research. *Qualitative research: A guide to design and implementation*.

Mouza, C., Ottenbreit-Leftwich, A., & Yadav, A. (2022). *Professional development for in-service teachers: Research and practices in computing education.* Information Age Publishing.

Musaeus, L. H., & Musaeus, P. (2019). Computational thinking in the Danish high school: Learning coding, modeling, and content knowledge with NetLogo. *SIGCSE*, 913–919.

Nijenhuis-Voogt, J., Yeni, S., & Barendsen, E. (2022). Integrating CT into biology: Using decision tree models to classify cell types. *CTE-STEM 2022 Conference.* https://doi.org/10.34641/ctestem.2022.460

NRC. (2010). *Report of a workshop on the scope and nature of computational thinking.* National Academies Press.

Parsazadeh, N., Cheng, P.-Y., Wu, T.-T., & Huang, Y.-M. (2021). Integrating computational thinking concept into digital storytelling to improve learners' motivation and performance. *Journal of Educational Computing Research, 59*(3), 470–495. https://doi.org/10.1177/0735633120967315

Puentedura, R. (2010). SAMR and TPCK: Intro to advanced practice. http://hippasus.com/resources/sweden2010/SAMR_TPCK_IntroToAdvancedPractice.pdf.

Sands, P., Yadav, A., & Good, J. (2018). Computational thinking in K-12: In-service teacher perceptions of computational thinking. In M. S. Khine (Ed.), *Computational thinking in the STEM disciplines: Foundations and research highlights* (pp. 151–164). Springer International Publishing. https://doi.org/10.1007/978-3-319-93566-9_8.

Selby, C. C. (2015). Relationships: Computational thinking, pedagogy of programming, and bloom's taxonomy. *Proceedings of the workshop in primary and secondary computing education.* https://doi.org/10.1145/2818314.2818315

Shreiner, T. L., & Guzdial, M. (2022). The information won't just sink in: Helping teachers provide technology-assisted data literacy instruction in social studies. *British Journal of Educational Technology, 53*(5), 1134–1158. https://doi.org/10.1111/bjet.13255

Stake, R. E. (2006). Cross-case analysis. In *Multiple case study analysis* (Vols. 39–77).

Tang, X., Yin, Y., Lin, Q., Hadad, R., & Zhai, X. (2020). Assessing computational thinking: A systematic review of empirical studies. *Computers & Education, 148*, Article 103798. https://doi.org/10.1016/j.compedu.2019.103798

Teo, T. (2011). Factors influencing teachers' intention to use technology: Model development and test. *Computers & Education, 57*(4), 2432–2440. https://doi.org/10.1016/j.compedu.2011.06.008

Tress, G., Tress, B., & Fry, G. (2005). Clarifying integrative research concepts in landscape ecology. *Landscape Ecology, 20*(4), 479–493. https://doi.org/10.1007/s10980-004-3290-4

Tsortanidou, X., Daradoumis, T., & Barberá, E. (2019). Connecting moments of creativity, computational thinking, collaboration and new media literacy skills. *Information and Learning Sciences, 120*(11/12), 704–722. https://doi.org/10.1108/ILS-05-2019-0042

Vinayakumar, R., Soman, K., & Menon, P. (2018). Digital storytelling using scratch: Engaging children towards digital storytelling. *2018 9th international conference on computing, communication and networking technologies (ICCCNT).* https://doi.org/10.1109/ICCCNT.2018.8493941

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology, 25*(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35.

Yadav, A., Hong, H., & Stephenson, C. (2016). Computational thinking for all: Pedagogical approaches to embedding 21st century problem solving in K-12 classrooms. *TechTrends, 60*(6), 565–568. https://doi.org/10.1007/s11528-016-0087-7

Yadav, A., Stephenson, C., & Hong, H. (2017). Computational thinking for teacher education. *Communications of the ACM, 60*(4), 55–62. https://doi.org/10.1145/2994591

Yeni, S., & Gecu-Parmaksiz, Z. (2016). Pre-service special education teachers acceptance and use of ICT: A structural equation model. *Journal of Education and Training Studies, 4*(12), 118–125.

Yeni, S., Grgurina, N., Saeli, M., Hermans, F., Tolboom, J., & Barendsen, E. (2023). Interdisciplinary integration of computational thinking in K-12 education: A systematic review. *Informatics in Education*. https://doi.org/10.15388/infedu.2024.08.

Yeni, S., Nijenhuis-Voogt, J., Hermans, F., & Barendsen, E. (2022). An integration of computational thinking and language arts: The contribution of digital storytelling to students' learning. *Proceedings of the 17th Workshop in Primary and Secondary Computing Education*, 1–10. https://doi.org/10.1145/3556787.3556858

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# Digital technologies and social sustainability in the digital transformation age: a systematic analysis and research agenda

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## Abstract

**Purpose** – This paper aims to systematically review the constructive effects of digital transformation (DT) on social sustainability, examining its impact across democracy and governance, social cohesion, quality of life, equality and diversity. It emphasizes the need for appropriate frameworks that incorporate DT strategies in organizational practices to improve social sustainability.

**Design/methodology/approach** – A systematic literature review was carried out through Web of Science and Scopus databases to identify the distinctive papers that explored the impact of DT on social sustainability. It analyzes how various digital technologies, like Internet of Things, cloud computing and mobile computing, can be strategically embedded in organizational practices to optimize social sustainability outcomes.

**Findings** – This study reveals that although DT significantly enhances operational capabilities and consumer experiences, its integration into social sustainability practices is often overlooked. It proposes a novel framework that aligns digital capabilities with sustainability goals, aiming to enrich organizational performance and societal welfare. This paper identifies dynamic capabilities as crucial for sustaining competitive advantage in a digitally transformed business landscape.

**Research limitations/implications** – The primary limitation is the reliance on secondary data, which may not fully capture the rapid advancements in DT. Future research should focus on empirical studies to validate the proposed framework and explore the dynamic capabilities required for integrating DT in social sustainability practices.

**Originality/value** – This study extends the discourse on DT by linking it explicitly with social sustainability, presenting a structured analysis that highlights the need for strategic integration of digital technologies within organizational sustainability practices. It fills a gap in the literature by proposing a comprehensive framework

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for organizations to follow, thereby contributing to the theoretical and practical understanding of DT's role in enhancing social sustainability.

**Keywords** Digital transformation, Social sustainability, Internet of Things (IoT), Democracy and governance, Social cohesion, Quality of life, equality and diversity

**Paper type** Literature review



## 1. Introduction

In recent years, the concept of digital transformation (DT) has gained significant attention across various sectors due to its profound impact on operational processes, business models and market structures (Holzinger *et al.*, 2021; Mondejar *et al.*, 2021; Khan *et al.*, 2024). DT refers to integrating digital technology into all business areas, fundamentally changing how organizations operate and deliver customer value (Bologa *et al.*, 2017). Similarly, DT can meet the needs of the United Nations Sustainable Development Goals (SDGs) by 2030 (Ziadlou, 2021). In the age of digital revolution, DT is a new way of doing business using digital technologies, such as robotics, cloud, social and mobile computing and analytics, leading to significant advances in consumer experiences and operational capabilities (Yaqub and Alsabban, 2023). DT has encouraged new business models that have disrupted global marketplaces and businesses (Brenner, 2018). As a result, traditional businesses have been shattered by the shock waves of DT, resulting from the entry of digitally savvy firms (Maley *et al.*, 2024; Rahi *et al.*, 2019). For instance, LinkedIn is the world's most popular online social networking site for job seekers (Navallas *et al.*, 2024). Amazon, the world's largest bookseller, is a software company (Cabezas-Clavijo *et al.*, 2024). Google is the world's largest online pure-play advertising company. These disruptions apply through digital technologies, i.e. cloud, Internet of Things (IoT), big data, machine learning, social and mobile computing (Manzoor *et al.*, 2024). It has been noted that the impact of DT is far-reaching and extends beyond customer behavior or companies to other domains, such as social dynamics and health care (Aldoseri *et al.*, 2024). In addition, the DT is expected to correct the sustainability triangle, i.e. social sustainability (Yuen *et al.*, 2024). Although digital technologies are primarily efficient, other factors have enabled DT (Gillani *et al.*, 2024). These include consumer attitudes and expectations, data availability and digital competition (Kao *et al.*, 2024; Khan *et al.*, 2022). In addition, advances in digital technology improve human rights, child labor and sustainable education (Aldoseri *et al.*, 2024; Ramaano, 2022a, 2022b, 2022c, 2022d). Therefore, more comprehensive studies are needed to understand better the effects of DT on different topics that have been overlooked in the literature, such as the influence on children, society, gender equality and human rights. Protecting human rights against abuse by those who are more powerful, as well as community-based health care, is a top challenge and requires more DT attention (Kickbusch *et al.*, 2021).

While digital technologies have profoundly enhanced various aspects of social sustainability (Weber *et al.*, 2022; Xiao and Su, 2022), a distinct gap exists in comprehensively understanding and integrating these advancements within organizational strategies to optimize their potential (Groenewald *et al.*, 2024). This research identifies a crucial research gap in the systematic integration of DT strategies with social sustainability goals within organizations. Existing literature primarily explores the benefits and applications of digital technologies such as the IoT, cloud computing and mobile computing on dimensions like democracy, social cohesion and quality of life. However, there needs to be more insight into how these technologies can be strategically embedded into organizational practices to enhance social sustainability systematically. In addition, the research underscores the need for frameworks that align digital capabilities with long-term sustainability objectives, suggesting an emerging area of focus on developing dynamic capabilities that support sustainable business models in the digital age.

The research objective of this study is to systematically analyze the effects of DT on social sustainability, particularly focusing on democracy and governance, social cohesion, quality of life, equality and diversity. This study aims to categorize the impacts of various digital technologies on these dimensions of social sustainability and to propose a comprehensive framework that integrates DT strategies with organizational performance and capabilities to enhance social sustainability. This will help understand the constructive effects of DT on social sustainability domains and inform the development of strategies that leverage digital technologies for enhanced organizational and social outcomes.

The structure of this article is organized as follows: Section 2 explains the concept of DT and its relationship to social and economic sustainability. Section 3 describes the methodology adopted for the study. Section 4 presents the results and provides a theoretical framework for understanding the constructive effect of DT on social sustainability. Section 5 discusses the key implications of this study, proposes an agenda for future research, and concludes the article.

## 2. Theoretical background

### *2.1 Digital transformations*

Business organizations have been forced to transform their businesses digitally due to the relentless intrusion of novel digital technologies into the market (Singh and Hess, 2020). DT has gained strategic importance as a key agenda of senior officials (Vial, 2019). In the literature, different definitions describe the DT. The current literature gives us a good understanding of DT and how it affects our lives in various ways. According to Horlacher and Hess (2016), DT is:

> The use of new digital technologies (social media, mobile, analytics or embedded devices) to enable major business improvements (such as enhancing customer experience, streamlining operations or creating new business models) as cited in (Paavola *et al.*, 2017, p. 2).

This concept encapsulates DT as a process examining how current and future digital technologies affect business models. Accordingly, DT is a company initiative to use new capabilities by leveraging digital technologies to change organizations' strategies and tasks (Li, 2020). It allows the integration of digital technology into existing business models, allowing organizations to change how they deliver products and services to their customers. More recently, Vial (2019, p. 118) stated that it is "a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies." From these different perspectives, DT is not the only initiative to improve specific organizational functions. Still, it is a process that causes fundamental changes in companies and opens up new opportunities for improvement.

Moreover, DT is not just an organizational process but a trend that drives change in society and industry (Groenewald *et al.*, 2024; Pappas *et al.*, 2023; Vial, 2019). It is essential to note how DT differs from digitalization and digitization. The digital representation of physical objects or attributes is referred to as digitization. DT is a business transformation that can be achieved through digitalization. In this article, we discuss DT in the context of social sustainability because, as previously stated, the effects of DT on social sustainability are limited. However, it is important to acknowledge that DTs have significant implications for economic sustainability, especially given the interconnected nature of social and economic factors in sustainability practices (Ramaano, 2022a, 2022b, 2022c, 2022d, 2023a, 2023b). Thus, while this study focuses on social sustainability, it also touches upon the broader impacts of DT on economic sustainability, recognizing that advancements in digital technologies not only enhance social outcomes but also drive economic growth, operational efficiencies and market competitiveness, which are integral to achieving SDGs.

### *2.2 Social sustainability*

From a business perspective, social sustainability aims to secure the spiritual and sociocultural needs of the people equitably. Therefore, everyone's needs are different, and these needs are affected by the current state of society (Ramaano, 2022a, 2022b, 2022c, 2022d; Assefa and Frostell, 2007). In other words, social sustainability can manage the negative and positive effects of systems, processes, companies and activities on people's social lives. In corporations, the areas that integrate the social sustainability concept include but are not limited to cultural competence, community resilience, product responsibility, wellness, social responsibility and justice, practices and decent working conditions, fair labor practices, human rights, health and social equity (Balaman, 2019; Ramaano, 2022a, 2022b, 2022c, 2022d). According to Mohamed *et al.* (2020), social sustainability measures human welfare. According to the Western Australia Council of Social Services:

> Social sustainability occurs when the formal and informal processes; systems; structures; and relationships actively support the capacity of current and future generations to create healthy and liveable communities. Socially sustainable communities are equitable, diverse, connected, and democratic and provide a good quality of life (Mani and Delgado, 2019, p. 17).

"Social sustainability" is the neglected component of sustainability (Kandachar, 2014).

Social sustainability, however, can only be fully addressed with considering its close ties to economic sustainability (Hariram *et al.*, 2023). Over the past decades, our world has predominantly focused on "economic sustainability (Jeronen, 2023). Although this approach has provided widespread material well-being in some parts of the world, a significant portion of the global population still struggles to make ends meet (Lavell *et al.* (2023). Therefore, sustainable practices are necessary to create maximum value for human well-being, including social and economic dimensions (Ramaano, 2023a, 2023b). As companies adopt DT strategies, they must consider "social sustainability practices" alongside "economic sustainability practices" to develop business models that not only foster social equity but also ensure long-term economic viability (Kwilinski, 2023; Azapagic *et al.*, 2016). This comprehensive approach is essential for reinforcing the literature on sustainability, as the intersection of social and economic factors is crucial for achieving the broader objectives of the SDGs, including poverty reduction, equitable economic growth and social inclusion (Van Zanten and van Tulder, 2021). In addition, touching on environmental sustainability aspects (Ramaano, 2023a, 2023b), even briefly, within the context of DT is essential to fully capture the holistic impact of digital technologies on sustainable development (Pachouri *et al.*, 2024).

### *2.3 The impact of digital transformation on social sustainability*

Digital technologies, i.e. Cloud, IoT, social platforms, mobile technologies, artificial intelligence (AI) and big data analytics, generate positive developments for industry and society (Bologa *et al.*, 2017; Rahi and Ghani, 2019). For example, 100 broadband satellite terminals were deployed in flood-affected districts of Pakistan, providing access to telemedicine services/applications services in rural areas. According to Junge and Straube (2020), deploying digital technologies in supply chain management and logistics positively impacts social sustainability. In addition, DT plays a key role in business flexibility, driving operational efficiency and achieving higher returns in the industry (Chandola, 2015). Organizations are launching new products, services and platforms that use digital technology to improve social sustainability. For instance, there has recently been a growing interest in AI among academics and executives. Driven by public interest and technological advances, AI is considered by some as an unparalleled revolutionary technology with the ability to change the nature of work (Brock and Wangenheim, 2019). Organizations mostly rely on cloud, mobile, big data, social technologies, analytics, IoT, AI and social networks to implement social sustainability practices that involve increased operational efficiencies (Bologa *et al.*, 2017). Cloud computing is the delivery of computing services (Youssef, 2012), i.e. networking, analytics, intelligence, databases, storage, servers, storage and databases, the cloud ("over the internet") to offer faster innovation, flexible resources and economies of scale. Mobile computing is a generic term encompassing many gadgets allowing people to access data and information from anywhere. In contrast, Big data and analytics tools assist businesses in identifying new growth opportunities and creating entirely new types of companies capable of integrating and analyzing industry data (Urbinati *et al.*, 2019).

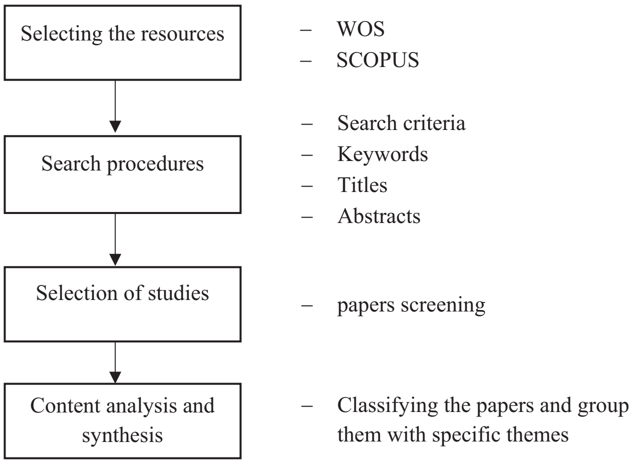
The convergence of social sustainability and digitalization extends beyond the organizational and industrial levels to the national level, significantly impacting economic sustainability. For instance, ElMassah and Mohieldin (2020) studied how countries worldwide are achieving the SDGs and how DT plays a critical role in these efforts. This synergy between social and economic sustainability is especially significant as digital technologies can spur economic development and provide employment opportunities, which are deemed critical in attaining the goals of the SDG paradigm (Sparviero and Ragnedda, 2021). Therefore, integrating DT with social and economic sustainability practices is essential for building resilient, equitable and prosperous societies.

## 3. Research method

This study uses a postpositivist research paradigm suitable for systematic literature reviews (SLRs), which synthesize existing theoretical and empirical findings without direct data collection. The postpositivist approach acknowledges the limitations of achieving absolute truth, yet it strives for objectivity through rigorous and structured scrutiny of theories against observed realities (Kabak *et al.*, 2024). This methodological framework underpins the study's purpose to explore and propose future research agendas regarding DT's impact on social sustainability. Using an SLR allows for a methodical examination of published literature, aligning with postpositivist principles prioritizing critical examination and logical analysis. The process, outlined by Bandara *et al.* (2011), involves a step-by-step method to systematically identify, assess and synthesize the relevant studies, detailed in Figure 1. This approach ensures a comprehensive analysis that contributes to a deeper understanding of digital technologies' influence on social sustainability domains.

### *3.1 Selecting the resources*

In this study, we used Web of Science (WoS) and Scopus databases to acquire relevant studies, as suggested by Wang and Waltman (2016). These are the most respected platforms for analyzing peer-reviewed literature: books, conference proceedings, scientific and social publications and other cross-disciplinary fields (Harzing and Alakangas, 2016; Singh *et al.*, 2021; Visser *et al.*, 2021; Rahi *et al.*, 2023).

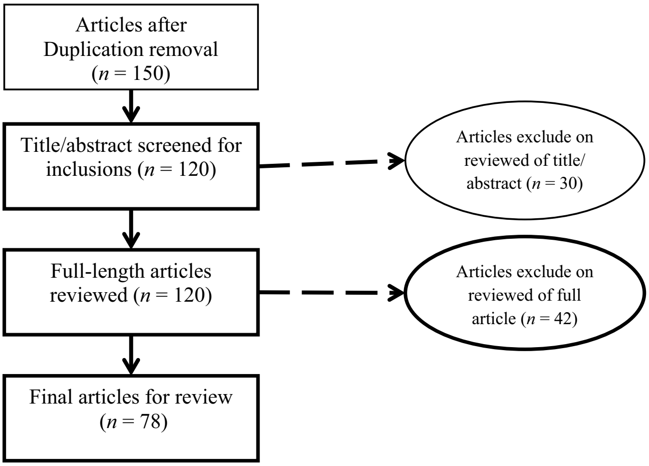



**Note:** Adapted from Feroz *et al.* (2021)

**Figure 1.** Systematic review process

*3.2 Search procedures*

Once the databases were searched, this study prepared a list of journals and studies in which they were published. We reviewed the previous studies in two phases. First, this study is to identify recent trends in the field of social sustainability. Second, we expanded our study to digital technology that enables DT. This study focused on digital technology included in the SMAC framework (Singh *et al.*, 2016), which refers to social, mobile, analytics and cloud and how they improve social initiatives in the organization. These four "digital technologies" can impact a business; their convergence is a configurative force transforming organizations and allowing service providers to create entirely new business models (Gimpel *et al.*, 2018). To ensure that no relevant study was missed, this study used keywords as research criteria (Levy and Ellis, 2006), which were used to retrieve relevant studies on available literature on DT and social sustainability. These terms and keywords were "digital transformation," "sustainable digital transformation," sustainability, "social sustainability," "equality and diversity," "democracy and governance," "social cohesio," and "quality of life" of the employees. In addition, the titles and abstracts of the articles published in the Scopus and WoS databases were examined. Later, each selected study's bibliography was inspected, which provided us with more information on the literature trends in our research domain. Contrariwise, as stated earlier, this study focuses only on the digital technologies that are under the SMAC umbrella. Therefore, in the second phase, we refined our keywords. After selecting resources and keywords, we selected previous studies that identified the positive effect of DT on the social sustainability domain by examining the Scopus and WoS databases, inspecting the selected journals and finally examining the references of the selected studies. This process of systematic review identified 150 relevant studies (see Figure 2).




**Note:** Moher *et al.* (2010)

**Figure 2.** Articles selection process – PRISMA flow diagram

### *3.3 Selection of studies*

To select the studies that provided evidence for the research questions, this study used a process presented in Figure 1. This systematic review included studies that fulfilled four criteria:

(1) it was necessary to include at least one of the aforementioned digital technologies in the article, and it had to be about social sustainability;

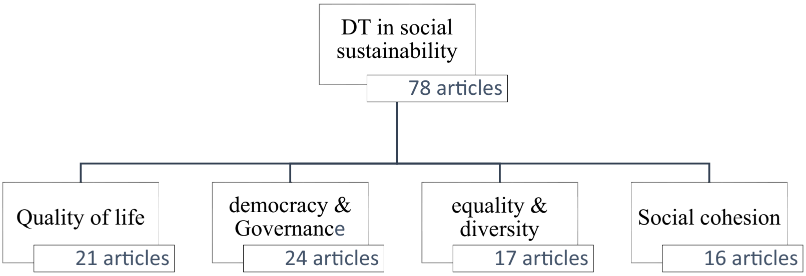
(2) the article had to be published in a peer-reviewed journal, regardless in the years of publication;

(3) having the English as the publication language or at least abstract in English; and

(4) if conference papers appeared in the Scopus and WoS databases, they were included. We did not include research notes or book chapters in our sample.

As stated earlier, 200 relevant articles were identified in the WoS and Scopus databases that fulfilled the basic criteria for this review: 90 on the WoS and 110 on Scopus. Duplication removal scrutiny excluded 50 articles, leaving 150 for abstract screening (see Figure 2). Furthermore, 30 articles were removed after the title and abstract screening, leaving 120 articles to be screened to determine their validity based on the inclusion criteria. Articles that fulfilled the quality standard were excluded. After the scrutiny, 78 studies fulfilled the selection criteria and were made a part of this review (see Figure 2). Among these 78 studies, 63 were found on both databases (WoS and Scopus), whereas 03 studies were found only on the WoS and 12 studies on Scopus, as shown in Figure 3.

For the final review of studies, we established specific criteria. We thoroughly screened all the full-text papers downloaded in detail and set aside a sample for review. Afterward, we prepared a table during the initial screening phase that contained the publication data such as paper title, author names, publication year, journal name and category (e.g. social and technology focus). Later, for a more comprehensive screening, we summarized each paper




**Source:** Created by authors

**Figure 3.** Identified digital transformation in social sustainability

separately in the table to fully grasp its scope, design, design and results. All papers were judged against the research relevance to choose a final sample.

## 4. Content analysis and synthesis

We conducted a thorough content analysis after finalizing the study sample. In addition, we analyzed the articles in the same systematic way as we searched for literature. Each article was categorized in publication, scope, location, technology emphasis and social effect using a detailed table. The chosen research articles examined how different digital technologies may help businesses increase their social sustainability by supporting various activities and operations. We dissected them thoroughly and drew the most important conclusions from them. We organized the papers into distinct categories and created a framework for future research. The findings are reported in the following section.

After a detailed literature review of the articles, it can be asserted that DTs can significantly influence and improve social responsibility. A substantial strand of evidence has emerged that contemporary technologies, including mobile, social, analytics, cloud, big data and IoTs, play a vital role in enhancing social cohesion, quality of life, gender equality and stabilizing governance structures (Brandtzaeg, 2020; Marlowe *et al.*, 2017; Milakovich, 2012; Neves and Vetere, 2019). For a better understanding, we have discussed the results of the relationship between digital technologies and the four dimensions of social sustainability in detail. Studies related to the role of digitalization in democracy and governance are highest compared to other dimensions of social sustainability.

In addition, we observed an upward trend in all four categories of annual publishing over time. This trend is expected to continue as more articles enter the literature in the coming years. In 2022, 2023 and 2024, the total number of publications was 10, 11 and 13, respectively, as shown in Figure 4. We could not find papers before the 2013s that met our requirements despite searching the literature without imposing any period constraints, as mentioned in the previous section. With the introduction of new digital technologies, more research with the search criteria may arise in the literature over time.

### *4.1 Quality of life*

Digital technologies can support autonomy and independence, assist age-related limitations and meaningfully contribute to the quality of life (Baker *et al.*, 2016; Quintana *et al.*, 2018). With the assimilation of AI and machine learning specifically designed for automated

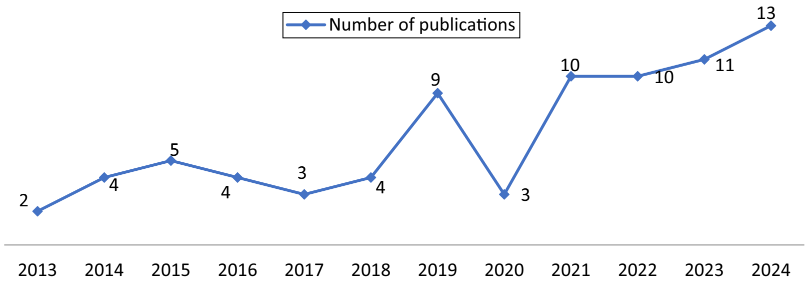



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**Figure 4.** Number of publications by years

therapy and clinical decision support, mobile health applications provide timely solutions to save precious lives (Hirschtritt and Insel, 2018). Some recent evidence is that digital technologies, especially IoTs, are developing interactivity between service providers, performance management, traffic management and quality services for smart cities (Senbekov *et al.*, 2020). A health-care system can be visualized and captured to support a safe environment. Especially in surgical settings, surgeons use digital visualization before operating an organ. Digitalization has also adequately measured resource consumption and reduced health-care system costs (Meiling *et al.*, 2021). Sophisticated technologies have also improved the quality of life by improving customer experience. A "crisis of immediacy" is faced by marketers to meet customer needs and receive personalized solutions, expertise and content in real-time while shopping. Using customer-facing apps including augmented reality, location-based mobile apps and video conferencing, businesses frequently get feedback to improve their shopping experience (Hoyer *et al.*, 2020). Certain digital technologies have also illuminated and advanced teaching practices to support the overall education system. Digital tools also assist students with vision impairments in acquiring self-determination and managing transition challenges (Camilleri and Camilleri, 2017; Pacheco *et al.*, 2018). In addition, digital financial literacy programs support financial inclusion, enhance saving behavior and facilitate the wealth creation process (Setiawan *et al.*, 2020). In general, these technologies directly contribute to the quality of life by improving mental and physical health through sound financial, educational and health-care systems.

### *4.2 Democracy and governance*

An engaged and informed citizenry is essential for the proper functioning of democracy. Technological advancements may facilitate the quality of mass participation in a representative democracy as they permit new social network growth and enrich political debate (Ali, 2020; Wilhelm, 2002). Information and communication technologies (ICT) networks may reduce excessive involvement of bureaucracy, register complaints and administrative abuses by automating government procedures that improve "people power" (Ali, 2020). Because information flow and transparency are enhanced with digital technologies, it can be used to restrict leaders and bureaucrats from making false claims, especially during political campaigns. Furthermore, e-democracy has emerged as a new form of democratic practice that can develop a resilient state against authoritarianism (Bannister and Connolly, 2018; López-López *et al.*, 2018; Sundberg, 2019). Thus, a region's ICT development directly improves political governance and institutional quality (Asongu and Nwachukwu, 2019). On the contrary, some researchers have also highlighted the negative or dark side of ICT usage. Especially in autocratic countries, the dissemination of information induces citizens' coordination and increases the probability of a mass mobilization wave, which eventually creates an unstable political environment (Hollyer *et al.*, 2019). When digital technologies control government where democracy is immature, bureaucratic powers use ICT networks for their interest (Ali, 2020). Gossart (2014) argued that digital technologies threaten democratic systems by generating "information cocoons." Accordingly, the information is tailored to citizens' fundamental sentiments and perceptions. These "information cocoons" allow information exchange between like-minded individuals only. With divergent opinions using ICTs, autocracy may create cognitive dissonance and manipulate the bounded rationality of voters (Valenzuela and Rojas, 2019).

### *4.3 Equality and diversity*

The role of digital and information technologies in promoting equality and diversity is also quite mixed. Digital technologies provide different opportunities for equal women's participation in entrepreneurial activities, financial markets and labor markets. Generally, working-class women have better social skills complemented by advanced digital literacy and higher education (Krieger-Boden and Sorgner, 2018). However, in various ways, ICTs disrupt how information flows to society. Inequalities based on knowledge, interest, age and class exist in political engagement and interactive media engagement. Mobile devices and social media usage are increasing the inequalities in participation between lower- and higher-skilled users (Prior, 2007; Valenzuela and Rojas, 2019). According to Gurumurthy *et al.* (2019), gender equality in job status and pay is at high risk of being overturned by automation-led job displacement in different sectors. Despite enormous efforts to enhance ICT adoption through legislative reforms and broadband plans, there are still prevalent gender inequalities in terms of digital literacy, ownership of digital devices and access to technology (Michell *et al.*, 2018). ICT can be a powerful mechanism for the social and political empowerment of females around the globe only if gender dimensions of ICT, including capacity-building opportunities, use and access, are unambiguously recognized and addressed.

### *4.4 Social cohesion*

The prompt transformation and continuous proliferation of social media platforms and digitalization extensively impact people's social connections (Marlowe *et al.*, 2017). ICTs have benefited inclusive development, social capital formation and social cohesion (Thapa *et al.*, 2012). Miklian and Hoelscher (2017) also highlighted that DTs could mitigate urban digital disparities to support community development, human security and conflict resolution, particularly in emerging economies. However, the effect of ICTs and community networks on social capital depends on different factors, including income and education level (Beckers *et al.*, 2005). There is also evidence related to the detrimental effects of digital technologies on social cohesion. For instance, Lybeck *et al.* (2023) argued that social media usage and digitalization reproduced prevailing social disparities for individuals with restricted online access. These anomalies and lack of access are potentially influenced by age, language barriers, education levels, literacy and economic status (Buthelezi *et al.*, 2024). At a fundamental level, digital technologies have transformed the nature of social interactions, creations and connections, allowing businesses to 'commoditize' human connectedness (Marlowe *et al.*, 2017).

## 5. Discussion

This study focuses on the domains of social sustainability where "digital technologies" influence the ways and procedures through which quality of life, equality and diversity, democracy and Governance and social cohesion are identified and managed within the organizations. In other words, social sustainability is a proactive approach to monitoring and recognizing company impacts on workers, employees in the supply chains, buyers and local communities. Organizations that emphasize the relevance of social sustainability recognize the significance of their interactions with people, communities and society (Ferreira *et al.*, 2023). According to the findings of this study, digital technologies offer enterprises a unique opportunity to create new socially conscious business models or adapt existing business models to incorporate socially sustainable practices. In either scenario, DT boosts social sustainability.

This research further emphasizes the unprecedented potential that digital technology offers for expanding the impact on the social sustainability sector, a potential that was only beginning to emerge a decade ago. For instance, the IoT enables employees to work remotely, enhancing both employee well-being and productivity (Adama and Michell, 2018; Papa *et al.*, 2020). In addition, advancements in digital technologies also benefit governance, business creation, social life and policy implementation (Popkova *et al.*, 2022). Similarly, through sustainability practices, DT can create a unified platform for understanding and improving the social environment (Khan *et al.*, 2024). Current trends in digital sustainability have opened numerous opportunities for businesses to innovate on traditional business models, allowing organizations to compete on new fronts and seek competitive advantages in socially responsible ways (Oliveira *et al.*, 2024). However, more research is necessary to fully explore how DT trends in social sustainability can be strategically leveraged to secure a competitive edge.

This research also identifies a gap in the existing literature concerning the integration of social sustainability within DT strategies. While there is ample literature on the landscapes of digitalization in terms of social sustainability (Ferreira *et al.*, 2023), there is a clear need for studies that focus on the capabilities required to transform business models sustainably while incorporating digital technologies. This study, therefore, proposes a new research agenda that seeks to address these gaps by investigating the intersection of DT and social sustainability.

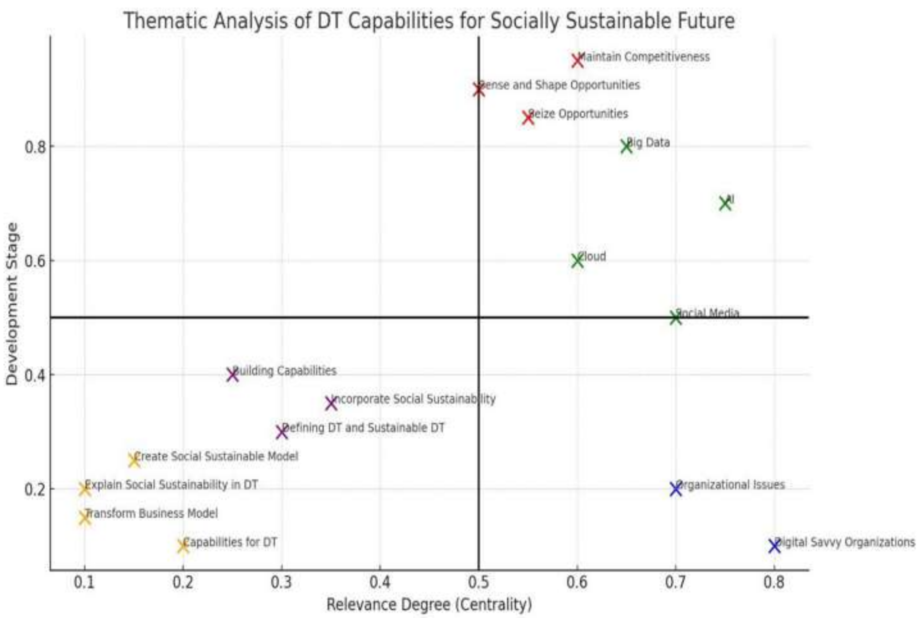
### *5.1 Agendum 1 – digital transformation capabilities for a socially sustainable future*

In social sustainability, some organizations are already digitally savvy when they enter, so they do not need to make significant changes to their business models. Because they already have a business strategy but must concentrate on organizational issues. With the help of advanced technologies such as cloud, social media, AI and big data, they can create opportunities for further innovation in terms of social sustainability. However, it is important to remember that with the organizational capacity to employ these technologies, they are useful for achieving sustainable goals. Capabilities must be dynamic and organizations must be able to make the necessary changes due to ongoing assessments of the internal and external social environment. For instance, dynamic capabilities delineate the potential of a business "to sense and shape opportunities and threats, to seize opportunities, and to maintain competitiveness through enhancing, combining, protecting, and when necessary, reconfiguring the business enterprise's intangible and tangible assets" (Teece, 2007). The capabilities required for DT in the context of social sustainability have received insufficient attention in the literature. Future research should, therefore, concentrate on DT from the perspective of dynamic capabilities, particularly how these capabilities can be developed and applied to achieve social sustainability goals.

The gap in the literature also exists when it comes to incorporating social sustainability into strategic decision-making. More research is needed to understand DT and its relationship to sustainability. In addition, we need to comprehend the phenomenon to build capabilities completely, as researchers have yet to agree on a single definition for DT. The thematic analysis plot, Figure 5, on "Digital Transformation (DT) Capabilities for a Socially Sustainable Future," categorizes key areas based on their relevance and developmental stage. It highlights Digital Savvy Organizations and Organizational Issues as well-developed and central, emphasizing their role in leveraging inherent digital capabilities and addressing dynamic organizational needs. Technology enablers like cloud, social media, AI and Big data are positioned as crucial and evolving, essential for innovation in social sustainability. Dynamic capabilities, including sensing opportunities and maintaining competitiveness, are seen as pivotal, well-developed and central to adapting to changing environments. The plot also identifies gaps and future research needs, such as defining DT in social sustainability and developing actionable, less developed, but increasingly relevant strategies. These insights from Figure 4 illustrate the current landscape and emphasize the need for focused research to integrate social sustainability effectively into DT strategies.

Therefore, first, researchers must establish a clear difference between DT and socially sustainable DT. Then, in the latter scenario, emphasis should be paid to the real capabilities required for the transformation. Incorporating "social sustainability" concepts into the DT and strategic planning process is unique, and further research is needed to comprehend the problem fully. In this context, this study suggests the following research issues for future research:

- How do we explain the inclusion of social Sustainability in DT?
- How can you create a socially sustainable model to grow the business?




**Source:** Created by authors

**Figure 5.** Thematic cluster analysis

- What capabilities do DTs require to help firms integrate social sustainability into their business models?
- What capabilities are required of businesses that want to transform their whole business model into socially sustainable?

*5.2 Agendum 2 – digitalization of social sustainability practices and organizational performance*

In Table 1, this study found that "digital technologies" such as cloud, mobile, analytics, social and big data are in some way driving social sustainability practices toward digitalization. Therefore, DT seems unavoidable, with ramifications for companies, industries and markets. New horizons are emerging to create new business models or stream existing ones. Alongside, the issue of "organizational performance" comes to the fore. Companies that seek to include social sustainability concepts into their "business models" want to know if such initiatives, independent of their social responsibility standings, may contribute to higher performance.

Creating and capturing customer value would be important for firms when considering changes to existing business models in line with social sustainability standards. Although previous studies have shown that consumer loyalty may be obtained via sustainability and social responsibility, improving overall organizational performance through social sustainability, digitalization remains unresolved. Businesses choose DT because they believe it will benefit them in the digital age. Otherwise, decision-makers would reject it as an important part of the DT process.

Therefore, another critical area of research should focus on the role of dynamic capabilities in this context. Organizations should explore how newly recognized capabilities can be used to refresh business models in a way that considers socially sustainable practices as part of a long-term strategy. More research is needed to explore the creation of socially sustainable DT capabilities and their impact on overall performance, including consumer loyalty, turnover and brand value. In this context, the following research questions are proposed:

*RQ1*. What role do socially sustainable DT capabilities play in improving organizational performance?

*RQ2*. What resources would be required to digitalize social sustainability practices?

*RQ3*. Can businesses take advantage of market competitiveness by digitalizing social sustainability practices?

*5.3 Agendum 3 – digital transformation strategy and social sustainability*

Although this study revealed that DT is a widely discussed topic among senior management, no reference to how social sustainability procedures can be integrated into the strategic decision-making process was found. The DT strategy calls for transforming products, processes and organizational aspects in response to the emergence of new technologies. The continued digitalization impacts how businesses operate, create new business opportunities and collaborate across industries. Business leaders' agendas are being reshaped by organizations' strategic responses to the transformation caused by digital technologies. Previously, technologies were viewed as supplementary support systems for an enterprise's main tasks, but emerging technologies are modifying that

**Table 1.** Digital transformation in social sustainability

| Category | Main findings | Relevant studies |
|---|---|---|
| Democracy and governance | From the review of relevant studies, this study shows that DT can be used to improve efficiency, effectiveness, transparency and openness to governance; promote sustainability; and increase accountability and citizen participation. In addition, digital technologies offer a level of security to combat cyber risks. Information technology has ensured that a policy decision taken by the senior management can be quickly executed and implemented at multiple locations, across the length and breadth of the organization. Nowadays, members of organizations can sit together and make collective decisions using digital technologies (e.g. social media). In addition, digital technologies have enabled us to draw conclusions from huge datasets and create automated reports to facilitate decisions without human intervention | Misuraca *et al.* (2012), Hensmans (2021), Sama *et al.* (2021), Zou and Zhao (2021), Boyer *et al.* (2016), Heavin and Power (2018), Androniceanu (2019), Tomor *et al.* (2019), Pereira *et al.* (2018), Ziemba (2019), Meyerhoff Nielsen (2019), Kostoska and Kocarev (2019), Seele (2016), Nesti (2020), Estevez and Janowski (2013), Schulz and Newig (2015), Ochara and Mawela (2015), Bouzguenda *et al.* (2019), Meilă (2018), Matthess and Kunkel (2020), Kuziemski and Misuraca (2020), Bellone *et al.* (2021), Pärli *et al.* (2021), Feeney and Porumbescu (2021), Martinez-Bravo and Wantchekon (2023), Crespy *et al.* (2024), Kraak and Niewolny (2024) |
| Quality of life | Digital technologies can help reduce bias, diversify talent pools and measure equality and diversity. According to the research referenced in the study, improving equality and diversity has a number of advantages for organizations in terms of creativity, profitability, decision-making and employee engagement | Xu *et al.*, 2024, Schneider and Kokshagina (2021), Zheng and Zhang (2023), Dias *et al.* (2022), Gkika *et al.* (2020), Bravi *et al.* (2018), Chan (2018), McKeown *et al.* (2018), Ahmad *et al.* (2020), Raman (2016), Demirkan *et al.* (2016), Nica (2016), Bughin and Chui (2013), Pande and Gomes (2015), Legner *et al.* (2017), Akter *et al.* (2020), Attaran *et al.* (2019), Evangelista *et al.* (2014), Fitzgerald *et al.* (2014), Sun *et al.* (2024) |
| Equality and diversity | Relevant studies has been shown that greater diversity, including gender diversity, have a favorable influence on an organization’s profitability, productivity and innovation. Employees can join the global workforce remotely through “mobile computing,” which allows competition and collaboration in markets. Likewise, machine learning is able to map candidates’ profiles to job descriptions, providing women and men an equal chance to be selected for a position. Furthermore, “blind recruitment” systems remove gender and names from the recruitment process, eliminating prejudices from the start | Lin and Xie (2024), Tuyen *et al.* (2023), Yang and Han (2023), Weber-Lewerenz and Vasiliu-Feltes (2022), Kohlrausch and Weber (2021), Govindan (2022); Ebrahimi *et al.* (2021), Suseno and Abbott (2021), Asi and Williams (2020), Krchová and Höesová (2021), Bejaković and Mrnjavac (2020), Urick (2020), Rajahonka and Villman (2019), Mihelj *et al.* (2019), Cherner and Fegely (2018), Akter (2016), Latukha and Selivanovskikh (2016), Michell *et al.* (2018), Goh *et al.* (2013) |

(*continued*)

**Table 1.** Continued

| Category | Main findings | Relevant studies |
|---|---|---|
| Social cohesion | Digital technologies can be used to improve collaboration, social networking, communication, content management and access to analytics data as well as customer and staff customer experience. The study also suggests that digital technologies can be used to build social cohesion, even where there are deep social gaps | Yang *et al.* (2024), Milutinović (2022), Shah and Shah (2024), Dionisio *et al.* (2024), Miciukiewicz and Vigar (2012), Abrahams (2016), Naranjo Gomez (2016), Thorpe and Lim (2013), Yang and Walker (2021), Stratigea *et al.* (2015), Zissis and Lekkas (2012), Lin (2018), Bindu *et al.* (2019), Van der Meer and Tolsma (2014), Marlowe *et al.* (2017), Wallace *et al.* (2017), Harris and Johns (2020), Ling *et al.* (2020) |

**Source:** Created by authors

paradigm. The ways value is created and captured are undergoing radical change due to digital technologies. This fact precludes a thorough understanding of organizational strategy and digitalization. Digital technologies should not be viewed as agents of improvement by senior management but as agents of transformation that send shockwaves throughout the organization.

In this regard, the DT strategy must include social sustainability as a core component. The process of redefining business models in response to new digital technologies is a continuous effort encompassing all aspects of core company operations, including social sustainability. Sustainability should not be viewed as an add-on but as an integral part of the strategic renewal process that DT ensures. Therefore, this study proposes the following research questions to guide future exploration of this alliance:

*RQ4*. How can social sustainability be included in digital company strategy?

*RQ5*. What digital business strategy is needed to start an enterprise on socially sustainable DT?

*RQ6*. What forces are driving businesses to carry out DT sustainably?

## 6. Conclusions

### *6.1 Contributions to theory*

This study makes several pivotal contributions to the theoretical landscape of social sustainability within the context of DT. It proposes new theoretical frameworks that merge DT strategies with organizational performance to enhance social sustainability. This integration encourages the scholarly community to evaluate and empirically test these frameworks across various industries and contexts. Such research aims to broaden our understanding of how specific digital technologies – such as AI, big data analytics and cloud computing – directly impact critical social dimensions like democracy, social cohesion, equality and quality of life.

In addition, “digital technologies” are changing how social sustainability problems are assessed and managed. However, the academic literature must understand how enterprises adapt to these technologies and the capabilities required to ensure that DT includes social sustainability. Therefore, this study focuses on the need for more in-depth studies to understand better the effects of DT in the domain of social sustainability. Specifically, one of the study’s objectives is to introduce digital technologies within the organization to manage its workforce socially and sustainably.

This study contributes to the literature by establishing a comprehensive framework that demonstrates how and where such DTs occur within the context of social sustainability. Using this framework, the study identifies key areas where DTs are prominent, such as in democracy and governance, quality of life, equality and diversity and social cohesion. The study also highlights the interconnectedness between social and economic sustainability, recognizing that advancements in digital technologies influence both domains. This dual impact contributes to a broader understanding of sustainability, particularly within the SDGs framework.

As previously indicated, future academic research can delve deeper into the issues revealed by our study, including capabilities, digitalization, organizational performance and the broader implications of DT. The study encourages researchers to explore the complex interplay between social and economic factors in sustainability, thereby broadening our understanding of how DT can be leveraged to achieve holistic sustainability outcomes. Our review will also support social sustainability scholars in connecting and collaborating on issues of mutual interest, fostering a more integrated approach to research in this field.

By using aa SLR from established databases, the paper provides a methodological blueprint for analyzing the impacts of digital technologies on various dimensions of social sustainability. The meticulous categorization of technological effects allows for a granular analysis, enhancing the depth and breadth of understanding in this area. This methodological rigor contributes to the academic community by offering a structured approach to dissecting complex interrelations between digital technologies and both social and economic outcomes, encouraging more detailed and systematic research in the future. Moreover, this approach aligns the study more closely with global sustainability initiatives, particularly the SDGs, thereby reinforcing its relevance and applicability.

### *6.2 Contributions to practice*

The study findings will help decision-makers in both private and public organizations identify and prioritize areas for investment. Our results can assist businesses in developing and implementing their social sustainability plans, resulting in a “win-win” situation for all parties involved. For instance, we observed that “digital technologies” provide companies with unique potential to build new socially sustainable business models or to use digital technology to integrate socially sustainable practices into existing business models. This understanding serves as a practical guide for decision-makers, helping them align their strategies with broader sustainability goals, including economic considerations, which are essential for achieving long-term success and resilience in a rapidly changing global environment.

These scenarios might be a launching pad for boardroom conversations about strategic goals and their implementation. Managers might begin by focusing on incremental improvements, such as digitalizing procedures and developing a better business strategy. In addition, the study’s implications extend to strategists and policymakers who aim to leverage technology for social good. The framework proposed guides the strategic implementation of DT and emphasizes the importance of continuous monitoring and adaptation based on social feedback mechanisms. This dynamic strategy keeps DT initiatives connected with changing social and economic goals, making them more resilient and relevant to rapid technological improvements.

Furthermore, the study's insights into potential pitfalls and ethical considerations provide a cautionary tale that can help practitioners navigate the moral implications of technological adoption in sensitive social contexts. The study's emphasis on ethical considerations is particularly important, as it ensures that DT efforts do not inadvertently harm the communities they are intended to benefit, thus promoting more responsible and sustainable technology use.

The study's originality lies in its holistic approach to examining the interplay between DT and social sustainability. The paper fills a significant gap in the literature by providing a structured analysis of current trends and future directions. It offers a novel theoretical and practical framework that advances academic understanding and serves as a guide for practical application. The value of this contribution is amplified by the increasing importance of DT and sustainability in contemporary societal and business contexts, making the findings relevant and timely for a broad audience.

## 7. Limitations and future research directions

This study presents several limitations that direct future research: *First*, given that our study used WOS and Scopus databases, some articles may have been overlooked in the data-compilation process. Future research should broaden the scope of database sources to include additional platforms such as Google Scholar, EBSCO and ProQuest. *Second*, reliance on secondary data may not reflect the rapid advancements in DT. Future studies should use empirical research to validate the proposed framework and identify the dynamic capabilities for integrating DT. *Third*, the study's use of published literature might miss recent technological developments. Incorporating grey literature like industry reports can provide more current insights, and establishing real-time data collection methods can ensure ongoing relevance.

## References

Abrahams, C. (2016), "Twenty years of social cohesion and nation-building in South Africa", *Journal of Southern African Studies*, Vol. 42 No. 1, pp. 95-107.

Adama, U.J. and Michell, K. (2018), "Towards examining the social implications of technology adoption on the well-being of facilities management professionals", *Journal of African Real Estate Research*, Vol. 3 No. 2, pp. 130-149.

Ahmad, N., Hoda, N. and Alahmari, F. (2020), "Developing a cloud-based mobile learning adoption model to promote sustainable education", *Sustainability*, Vol. 12 No. 8, p. 3126.

Akter, R. (2016), "Business sustainability in Bangladesh: an analysis of economic sustainability in ready-made garments industries", *J. Mgmt. & Sustainability*, Vol. 6, p. 149.

Akter, S., Michael, K., Uddin, M.R., McCarthy, G. and Rahman, M. (2020), "Transforming business using digital innovations: the application of AI, blockchain, cloud and data analytics", *Annals of Operations Research*, Vol. 308 Nos 1/2, pp. 1-33.

Aldoseri, A., Al-Khalifa, K.N. and Hamouda, A.M. (2024), "AI-powered innovation in digital transformation: key pillars and industry impact", *Sustainability*, Vol. 16 No. 5, p. 1790.

Ali, M.S.B. (2020), "Does ICT promote democracy similarly in developed and developing countries? A linear and nonlinear panel threshold framework", *Telematics and Informatics*, Vol. 50, p. 101382.

Androniceanu, A. (2019), "The social sustainability of smart cities: urban technological innovation, big data management, and the cognitive internet of things", *Geopolitics, History, and International Relations*, Vol. 11 No. 1, pp. 110-115.

Asi, Y.M. and Williams, C. (2020), "Equality through innovation: promoting women in the workplace in low-and middle-income countries with health information technology", *Journal of Social Issues*, Vol. 76 No. 3, pp. 721-743.

Asongu, S.A. and Nwachukwu, J.C. (2019), "The role of openness in the effect of ICT on governance", *Information Technology for Development*, Vol. 25 No. 3, pp. 503-531.

Assefa, G. and Frostell, B. (2007), "Social sustainability and social acceptance in technology assessment: a case study of energy technologies", *Technology in Society*, Vol. 29 No. 1, pp. 63-78.

Attaran, M., Attaran, S. and Kirkland, D. (2019), "The need for digital workplace: increasing workforce productivity in the information age", *International Journal of Enterprise Information Systems (IJEIS)*, Vol. 15 No. 1, pp. 1-23.

Azapagic, A., Stamford, L., Youds, L. and Barteczko-Hibbert, C. (2016), "Towards sustainable production and consumption: a novel decision-support framework integrating economic, environmental and social sustainability (DESIRES)", *Computers and Chemical Engineering*, Vol. 91, pp. 93-103.

Baker, S., Waycott, J., Pedell, S., Hoang, T. and Ozanne, E. (2016), "Older people and social participation: from touch-screens to virtual realities", Paper presented at the International Symposium on Interactive Technology and Ageing Populations.

Balaman, S. (2019), "Decision-making for biomass-based production chains", *The Basic Concepts and Methodologies*, pp. 46-47.

Bandara, W., Miskon, S. and Fielt, E. (2011), "A systematic, tool-supported method for conducting literature reviews in information systems", Paper presented at the 19th European Conference on Information Systems (ECIS 2011).

Bannister, F. and Connolly, R. (2018), "The fourth power: ICT and the role of the administrative state in protecting democracy", *Information Polity*, Vol. 23 No. 3, pp. 307-323.

Beckers, D., van Gent, W., Iedema, J. and de Haan, J. (2005), "Effects of ICT on social cohesion: the Cyburg case", Paper presented at Digital Cities III. Information Technologies for Social Capital: Cross-cultural Perspectives, Berlin, Heidelberg.

Bejaković, P. and Mrnjavac, Ž. (2020), "The importance of digital literacy on the labour market", *Employee Relations: The International Journal*, Vol. 42 No. 4, pp. 921-932.

Bellone, C., Naselli, F. and Andreassi, F. (2021), "New governance path through digital platforms and the old urban planning process in Italy", *Sustainability*, Vol. 13 No. 12, p. 6911.

Bindu, N., Sankar, C.P. and Kumar, K.S. (2019), "From conventional governance to e-democracy: tracing the evolution of e-governance research trends using network analysis tools", *Government Information Quarterly*, Vol. 36 No. 3, pp. 385-399.

Bologa, R., Lupu, A.-R., Boja, C. and Georgescu, T.M. (2017), "Sustaining employability: a process for introducing cloud computing, big data, social networks, mobile programming and cybersecurity into academic curricula", *Sustainability*, Vol. 9 No. 12, p. 2235.

Bouzguenda, I., Alalouch, C. and Fava, N. (2019), "Towards smart sustainable cities: a review of the role digital citizen participation could play in advancing social sustainability", *Sustainable Cities and Society*, Vol. 50, p. 101627.

Boyer, R.H., Peterson, N.D., Arora, P. and Caldwell, K. (2016), "Five approaches to social sustainability and an integrated way forward", *Sustainability*, Vol. 8 No. 9, p. 878.

Brandtzaeg, P.B. (2020), "How mobile media impacts urban life: blending social cohesion and social distancing", *Interactions*, Vol. 27 No. 6, pp. 52-56.

Bravi, L., Murmura, F. and Santos, G. (2018), “Manufacturing labs: where new digital technologies help improve life quality”, *International Journal for Quality Research*, Vol. 12 No. 4, p. 957.

Brenner, B. (2018), “Transformative sustainable business models in the light of the digital imperative—a global business economics perspective”, *Sustainability*, Vol. 10 No. 12, p. 4428.

Brock, J.K.-U. and Wangenheim, F. (2019), “Demystifying AI: what digital transformation leaders can teach you about realistic artificial intelligence”, *California Management Review*, Vol. 61 No. 4, pp. 110-134.

Bughin, J. and Chui, M. (2013), “Evolution of the networked enterprise: mcKinsey global survey results”, McKinsey Quarterly, Spring, p. 29.

Buthelezi, S.P., Zondo, N.M., Nxumalo, L.T. and Vilakazi, M. (2024), “Determining the digital divide among people with disabilities in KwaZulu-Natal”, *South African Journal of Information Management*, Vol. 26 No. 1, p. 12.

Cabezas-Clavijo, Á., Magadán-Díaz, M., Rivas-García, J.I. and Sidorenko-Bautista, P. (2024), “This book is written by ChatGPT: a quantitative analysis of ChatGPT authorships through amazon.com”, Publishing Research Quarterly, pp. 1-17.

Camilleri, M.A. and Camilleri, A.C. (2017), “Digital learning resources and ubiquitous technologies in education”, *Technology, Knowledge and Learning*, Vol. 22 No. 1, pp. 65-82, doi: 10.1007/s10758-016-9287-7.

Chan, M. (2018), “Digital communications and psychological well-being across the life span: examining the intervening roles of social capital and civic engagement”, *Telematics and Informatics*, Vol. 35 No. 6, pp. 1744-1754.

Chandola, V. (2015), *Digital Transformation and Sustainability: Study and Analysis*, Harvard University, Cambridge.

Cherner, T. and Fegely, A. (2018), “Answering Damarin's call: how iOS apps approach diversity, equity, and multiculturalism”, *International Journal of Multicultural Education*, Vol. 20 No. 1, pp. 21-47.

Crespy, A., Moreira Ramalho, T. and Schmidt, V. (2024), “Beyond 'responsibility vs. responsiveness’: reconfigurations of EU economic governance in response to crises”, *Journal of European Public Policy*, Vol. 31 No. 4, pp. 925-949.

Demirkan, H., Spohrer, J.C. and Welser, J.J. (2016), “Digital innovation and strategic transformation”, *IT Professional*, Vol. 18 No. 6, pp. 14-18.

Dias, A.M., Carvalho, A.M. and Sampaio, P. (2022), “Quality 4.0: literature review analysis, definition and impacts of the digital transformation process on quality”, *International Journal of Quality and Reliability Management*, Vol. 39 No. 6, pp. 1312-1335.

Dionisio, M., de Souza Junior, S.J., Paula, F. and Pellanda, P.C. (2024), “The role of digital social innovations to address SDGs: a systematic review”, *Environment, Development and Sustainability*, Vol. 26 No. 3, pp. 5709-5734.

Ebrahimi, H.P., Schillo, R.S. and Bronson, K. (2021), “Systematic stakeholder inclusion in digital agriculture: a framework and application to Canada”, *Sustainability*, Vol. 13, p. 6879.

ElMassah, S. and Mohieldin, M. (2020), “Digital transformation and localizing the sustainable development goals (SDGs)”, *Ecological Economics*, Vol. 169, p. 106490.

Estevez, E. and Janowski, T. (2013), “Electronic governance for sustainable development—conceptual framework and state of research”, *Government Information Quarterly*, Vol. 30, pp. S94-S109.

Evangelista, R., Guerrieri, P. and Meliciani, V. (2014), “The economic impact of digital technologies in Europe”, *Economics of Innovation and New Technology*, Vol. 23 No. 8, pp. 802-824.

Feeney, M.K. and Porumbescu, G. (2021), “The limits of social media for public administration research and practice”, *Public Administration Review*, Vol. 81 No. 4, pp. 787-792.

Ferreira, J.J., Lopes, J.M., Gomes, S. and Rammal, H.G. (2023), "Industry 4.0 implementation: environmental and social sustainability in manufacturing multinational enterprises", *Journal of Cleaner Production*, Vol. 404, p. 136841.

Fitzgerald, M., Kruschwitz, N., Bonnet, D. and Welch, M. (2014), "Embracing digital technology: a new strategic imperative", *MIT Sloan Management Review*, Vol. 55 No. 2, p. 1.

Gillani, F., Chatha, K.A., Jajja, S.S., Cao, D. and Ma, X. (2024), "Unpacking digital transformation: identifying key enablers, transition stages and digital archetypes", *Technological Forecasting and Social Change*, Vol. 203, p. 123335.

Gimpel, H., Hosseini, S., Huber, R.X.R., Probst, L., Röglinger, M. and Faisst, U. (2018), "Structuring digital transformation: a framework of action fields and its application at ZEISS", *J. Inf. Technol. Theory Appl*, Vol. 19 No. 1, p. 3.

Gkika, E.C., Anagnostopoulos, T., Ntanos, S. and Kyriakopoulos, G.L. (2020), "User preferences on cloud computing and open innovation: a case study for university employees in Greece", *Journal of Open Innovation: Technology, Market, and Complexity*, Vol. 6 No. 2, p. 41.

Goh, K.-Y., Heng, C.-S. and Lin, Z. (2013), "Social media brand community and consumer behavior: quantifying the relative impact of user-and marketer-generated content", *Information Systems Research*, Vol. 24 No. 1, pp. 88-107.

Gossart, C. (2014), "Can digital technologies threaten democracy by creating information cocoons?", *Transforming Politics and Policy in the Digital Age*, IGI Global, Hershey, Pennsylvania, pp. 145-154.

Govindan, K. (2022), "Tunneling the barriers of blockchain technology in remanufacturing for achieving sustainable development goals: a circular manufacturing perspective", *Business Strategy and the Environment*, Vol. 31 No. 8, pp. 3769-3785.

Groenewald, C.A., Groenewald, E., Uy, F., Kilag, O.K., Abendan, C.F. and Dulog, S.M. (2024), "The future: trends and implications for organizational management", *International Multidisciplinary Journal of Research for Innovation, Sustainability, Excellence – ISSN*, pp. 114-120.

Gurumurthy, A., Chami, N. and Alemany, C. (2019), "Gender equality in the digital economy: emerging issues", Feminist Digital Justice Issue Paper, No. 1.

Hariram, N.P., Mekha, K.B., Suganthan, V. and Sudhakar, K. (2023), "Sustainalism: an integrated socio-economic-environmental model to address sustainable development and sustainability", *Sustainability*, Vol. 15 No. 13, p. 10682.

Harris, A. and Johns, A. (2020), "Youth, social cohesion and digital life: from risk and resilience to a global digital citizenship approach", *Journal of Sociology*, Vol. 57 No. 2, p. 1440783320919173.

Harzing, A.-W. and Alakangas, S. (2016), "Google Scholar, Scopus and the Web of Science: a longitudinal and cross-disciplinary comparison", *Scientometrics*, Vol. 106 No. 2, pp. 787-804.

Heavin, C. and Power, D.J. (2018), "Challenges for digital transformation–towards a conceptual decision support guide for managers", *Journal of Decision Systems*, Vol. 27 No. 1, pp. 38-45.

Hensmans, M. (2021), "Exploring the dark and bright sides of internet democracy: ethos-reversing and ethos-renewing digital transformation", *Technological Forecasting and Social Change*, Vol. 168, p. 120777.

Hirschtritt, M.E. and Insel, T.R. (2018), "Digital technologies in psychiatry: present and future", *Focus*, Vol. 16 No. 3, pp. 251-258.

Hollyer, J.R., Rosendorff, B.P. and Vreeland, J.R. (2019), "Transparency, protest and democratic stability", *British Journal of Political Science*, Vol. 49 No. 4, pp. 1251-1277.

Holzinger, A., Weippl, E., Tjoa, A.M. and Kieseberg, P. (2021), "Digital transformation for sustainable development goals (SDGs)-a security, safety and privacy perspective on ai", Paper presented at the International cross-domain conference for machine learning and knowledge extraction.

Horlacher, A. and Hess, T. (2016), "What does a chief digital officer do? Managerial tasks and roles of a new C-level position in the context of digital transformation", Paper presented at the 49th Hawaii International Conference on System Sciences (HICSS).

Hoyer, W.D., Kroschke, M., Schmitt, B., Kraume, K. and Shankar, V. (2020), "Transforming the customer experience through new technologies", *Journal of Interactive Marketing*, Vol. 51 No. 1, pp. 57-71.

Jeronen, E. (2023), "Economic sustainability", *Encyclopedia of Sustainable Management*, Springer International Publishing, Cham, pp. 1257-1263.

Junge, A.L. and Straube, F. (2020), "Sustainable supply chains–digital transformation technologies' impact on the social and environmental dimension", *Procedia Manufacturing*, Vol. 43, pp. 736-742.

Kabak, K.E., Hinckeldeyn, J. and Dekkers, R. (2024), "A systematic literature review into simulation for building operations management theory: reaching beyond positivism?", *Journal of Simulation*, pp. 1-29.

Kandachar, P. (2014), "Materials and social sustainability", *Materials Experience*, Butterworth-Heinemann, London, pp. 91-103.

Kao, L.-J., Chiu, C.-C., Lin, H.-T., Hung, Y.-W. and Lu, C.-C. (2024), "Unveiling the dimensions of digital transformation: a comprehensive taxonomy and assessment model for business", *Journal of Business Research*, Vol. 176, p. 114595.

Khan, S.W., Raza, S.H. and Zaman, U. (2022), "Remodeling digital marketplace through metaverse: a multi-path model of consumer neuroticism, parasocial relationships, social media influencers credibility, and openness to metaverse experience", *Pakistan Journal of Commerce and Social Sciences (PJCSS)*, Vol. 16 No. 3, pp. 337-365.

Khan, S., Subramanian, U. and Mutalib, P.A. (2024), "Gender and access to bank credit around the world during the COVID-19 pandemic: the mediating role of digital transformation", *Pakistan Journal of Commerce and Social Sciences (PJCSS)*, Vol. 18 No. 1, pp. 1-39.

Kickbusch, I., Piselli, D., Agrawal, A., Balicer, R., Banner, O., Adelhardt, M. and Lupton, D. (2021), "The lancet and financial times commission on governing health futures 2030: growing up in a digital world", *The Lancet*, Vol. 398 No. 10312, pp. 1727-1776.

Kohlrausch, B. and Weber, L. (2021), "Gender relations at the digitalised workplace: the interrelation between digitalisation, gender, and work", *Gender a Výzkum / Gender and Research*, Vol. 21 No. 2, pp. 13-31.

Kostoska, O. and Kocarev, L. (2019), "A novel ICT framework for sustainable development goals", *Sustainability*, Vol. 11 No. 7, p. 1961.

Kraak, V.I. and Niewolny, K.L. (2024), "A scoping review of food systems governance frameworks and models to develop a typology for social change movements to transform food systems for people and planetary health", *Sustainability*, Vol. 16 No. 4, p. 1469.

Krchová, H. and Höesová, K.Š. (2021), "Selected determinants of digital transformation and their influence on the number of women in the ICT sector", *Entrepreneurship and Sustainability Issues*, Vol. 8 No. 4, p. 524.

Krieger-Boden, C. and Sorgner, A. (2018), "Labor market opportunities for women in the digital age", *Economics*, Vol. 12 No. 1.

Kuziemski, M. and Misuraca, G. (2020), "AI governance in the public sector: three tales from the frontiers of automated decision-making in democratic settings", *Telecommunications Policy*, Vol. 44 No. 6, p. 101976.

Kwilinski, A. (2023), "The relationship between sustainable development and digital transformation: bibliometric analysis", *Virtual Economics*, Vol. 6 No. 3, pp. 56-69.

Latukha, M. and Selivanovskikh, L. (2016), "Talent management practices in IT companies from emerging markets: a comparative analysis of Russia, India, and China", *Journal of East-West Business*, Vol. 22 No. 3, pp. 168-197.

Lavell, A., McFarlane, C., Moore, H.L., Woodcraft, S. and Yap, C. (2023), "Pathways to urban equality through the sustainable development goals: modes of extreme poverty, resilience, and prosperity", *International Journal of Urban Sustainable Development*, Vol. 15 No. 1, pp. 215-229.

Legner, C., Eymann, T., Hess, T., Matt, C., Böhmann, T., Drews, P. and Ahlemann, F. (2017), "Digitalization: opportunity and challenge for the business and information systems engineering community", *Business and Information Systems Engineering*, Vol. 59 No. 4, pp. 301-308.

Levy, Y. and Ellis, T.J. (2006), "A systems approach to conduct an effective literature review in support of information systems research", *Informing Science*, Vol. 9, p. 9.

Li, F. (2020), "The digital transformation of business models in the creative industries: a holistic framework and emerging trends", *Technovation*, Vols 92/93, p. 102012.

Lin, Y. (2018), "A comparison of selected Western and Chinese smart governance: the application of ICT in governmental management, participation and collaboration", *Telecommunications Policy*, Vol. 42 No. 10, pp. 800-809.

Lin, B. and Xie, Y. (2024), "Impacts of digital transformation on corporate green technology innovation: do board characteristics play a role?", *Corporate Social Responsibility and Environmental Management*, Vol. 31 No. 3, pp. 1741-1755.

Ling, S., Landon, A., Tarrant, M. and Rubin, D. (2020), "Sustainability education and environmental worldviews: shifting a paradigm", *Sustainability*, Vol. 12 No. 19, p. 8258.

López-López, V., Iglesias-Antelo, S., Vázquez-Sanmartín, A., Connolly, R. and Bannister, F. (2018), "E-government, transparency and reputation: an empirical study of Spanish local government", *Information Systems Management*, Vol. 35 No. 4, pp. 276-293.

Lybeck, R., Koiranen, I. and Koivula, A. (2023), "From digital divide to digital capital: the role of education and digital skills in social media participation", *Universal Access in the Information Society*, Vol. 23 No. 4, pp. 1-13.

McKeown, J.K., Parry, D.C. and Light, T.P. (2018), "'My iPhone changed my life': how digital technologies can enable women's consumption of online sexually explicit materials", *Sexuality and Culture*, Vol. 22 No. 2, pp. 340-354.

Maley, J.F., Dabić, M., Neher, A., Wuersch, L., Martin, L. and Kiessling, T. (2024), "Performance management in a rapidly changing world: implications for talent management", Management Decision.

Mani, J. and Delgado, C. (2019), *Supply Chain Social Sustainability for Manufacturing: Measurement and Performance Outcomes from India*, Springer, Singapore.

Manzoor, A., Qureshi, M.A., Kidney, E. and Longo, L. (2024), "A review on machine learning methods for customer churn prediction and recommendations for business practitioners", IEEE Access.

Marlowe, J.M., Bartley, A. and Collins, F. (2017), "Digital belongings: the intersections of social cohesion, connectivity and digital media", *Ethnicities*, Vol. 17 No. 1, pp. 85-102.

Matthess, M. and Kunkel, S. (2020), "Structural change and digitalization in developing countries: conceptually linking the two transformations", *Technology in Society*, Vol. 63, p. 101428.

Martinez-Bravo, M. and Wantchekon, L. (2023), "Political economy and structural transformation: democracy, regulation and public investment", *Oxford Development Studies*, Vol. 51 No. 4, pp. 417-435.

Meilă, A.D. (2018), "Sustainable urban mobility in the sharing economy: digital platforms, collaborative governance, and innovative transportation", *Contemporary Readings in Law and Social Justice*, Vol. 10 No. 1, pp. 130-136.

Meiling, L., Yahya, F., Waqas, M., Shaohua, Z., Ali, S.A. and Hania, A. (2021), "Boosting sustainability in healthcare sector through fintech: analyzing the moderating role of financial and ICT development", *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*, Vol. 58, p. 00469580211028174.

Meyerhoff Nielsen, M. (2019), "Governance lessons from Denmark's digital transformation", Paper presented at the Proceedings of the 20th Annual International Conference on Digital Government Research.

Michell, D., Szabo, C., Falkner, K. and Szorenyi, A. (2018), "Towards a socio-ecological framework to address gender inequity in computer science", *Computers and Education*, Vol. 126, pp. 324-333.

Miciukiewicz, K. and Vigar, G. (2012), "Mobility and social cohesion in the splintered city: challenging technocentric transport research and policy-making practices", *Urban Studies*, Vol. 49 No. 9, pp. 1941-1957.

Mihelj, S., Leguina, A. and Downey, J. (2019), "Culture is digital: cultural participation, diversity and the digital divide", *New Media and Society*, Vol. 21 No. 7, pp. 1465-1485.

Miklian, J. and Hoelscher, K. (2017), "Smart cities, mobile technologies and social cohesion in India", *Indian Journal of Human Development*, Vol. 11 No. 1, pp. 1-16.

Milakovich, M.E. (2012), *Digital Governance: New Technologies for Improving Public Service and Participation*, Routledge, New York.

Milutinović, P. (2022), "Digital public policy and E-Governance as factors of the enhanced socio-economic cohesion in the European Union", *Kultura Polisa*, Vol. 19 No. 4, pp. 146-163.

Misuraca, G., Broster, D. and Centeno, C. (2012), "Digital Europe 2030: designing scenarios for ICT in future governance and policy making", *Government Information Quarterly*, Vol. 29, pp. S121-S131.

Mohamed, A.-M.O., Paleologos, E.K. and Howari, F. (2020), *Pollution Assessment for Sustainable Practices in Applied Sciences and Engineering*, Butterworth-Heinemann, London.

Mondejar, M.E., Avtar, R., Diaz, H.L.B., Dubey, R.K., Esteban, J., Gómez-Morales, A. and Prasad, K. A. (2021), "Digitalization to achieve sustainable development goals: steps towards a smart green planet", *Science of The Total Environment*, Vol. 794, p. 148539.

Naranjo Gomez, J.M. (2016), "Impacts on the social cohesion of mainland Spain's future motorway and high-speed rail networks", *Sustainability*, Vol. 8 No. 7, p. 624.

Navallas, B., Campo, C. and Camacho-Miñano, M-D-M (2024), "Professional contacts and the decision to become an auditor. An analysis using LinkedIn", *Accounting Education*, Vol. 33 No. 1, pp. 27-45.

Nesti, G. (2020), "Defining and assessing the transformational nature of smart city governance: insights from four European cases", *International Review of Administrative Sciences*, Vol. 86 No. 1, pp. 20-37.

Neves, B.B. and Vetere, F. (2019), "Ageing and emerging digital technologies", *Ageing and Digital Technology*, Springer, Singapore, pp. 1-14.

Nica, E. (2016), "Will technological unemployment and workplace automation generate greater capital–labor income imbalances?", *Economics, Management, and Financial Markets*, Vol. 11 No. 4, pp. 68-74.

Ochara, N.M. and Mawela, T. (2015), "Enabling social sustainability of e-participation through mobile technology", *Information Technology for Development*, Vol. 21 No. 2, pp. 205-228.

Oliveira, U.R., Menezes, R.P. and Fernandes, V.A. (2024), "A systematic literature review on corporate sustainability: contributions, barriers, innovations and future possibilities", *Environment, Development and Sustainability*, Vol. 26 No. 2, pp. 3045-3079.

Paavola, R., Hallikainen, P. and Elbanna, A. (2017), “Role of middle managers in modular digital transformation: the case of Servu”, *Journal Name Missing*, p. 58.

Pacheco, E., Lips, M. and Yoong, P. (2018), “Transition 2.0: digital technologies, higher education, and vision impairment”, *The Internet and Higher Education*, Vol. 37, pp. 1-10.

Pachouri, V., Singh, R., Gehlot, A., Pandey, S., Akram, S.V. and Abbas, M. (2024), “Empowering sustainability in the built environment: a technological lens on industry 4.0 enablers”, *Technology in Society*, Vol. 76, p. 102427.

Pande, S. and Gomes, N. (2015), “Leveraging mobile devices for human resource information systems”, *International Journal of Business Information Systems*, Vol. 20 No. 1, pp. 23-40.

Papa, A., Mital, M., Pisano, P. and Del Giudice, M. (2020), “E-health and wellbeing monitoring using smart healthcare devices: an empirical investigation”, *Technological Forecasting and Social Change*, Vol. 153, p. 119226.

Pappas, I.O., Mikalef, P., Dwivedi, Y.K., Jaccheri, L. and Krogstie, J. (2023), “Responsible digital transformation for a sustainable society”, *Information Systems Frontiers*, Vol. 25 No. 3, pp. 945-953.

Pärli, R., Fischer, M. and Lieberherr, E. (2021), “Information exchange networks among actors for the implementation of SDGs”, *Current Research in Environmental Sustainability*, Vol. 3, p. 100049.

Pereira, G.V., Parycek, P., Falco, E. and Kleinhans, R. (2018), “Smart governance in the context of smart cities: a literature review”, *Information Polity*, Vol. 23 No. 2, pp. 143-162.

Popkova, E.G., De Bernardi, P., Tyurina, Y.G. and Sergi, B.S. (2022), “A theory of digital technology advancement to address the grand challenges of sustainable development”, *Technology in Society*, Vol. 68, p. 101831.

Prior, M. (2007), *Post-Broadcast Democracy: How Media Choice Increases Inequality in Political Involvement and Polarizes Elections*, Cambridge University Press, Cambridge.

Quintana, D., Cervantes, A., Sáez, Y. and Isasi, P. (2018), “Internet use and psychological well-being at advanced age: evidence from the English longitudinal study of aging”, *International Journal of Environmental Research and Public Health*, Vol. 15 No. 3, p. 480.

Rahi, S. and Ghani, M. (2019), “Does gamified elements influence on user’s intention to adopt and intention to recommend internet banking?”, *The International Journal of Information and Learning Technology*, Vol. 36 No. 1, pp. 2-20.

Rahi, S., Alghizzawi, M. and Ngah, A.H. (2023), “Factors influence user’s intention to continue use of e-banking during COVID-19 pandemic: the nexus between self-determination and expectation confirmation model”, *EuroMed Journal of Business*, Vol. 18 No. 3, pp. 380-396.

Rahi, S., Othman Mansour, M.M., Alghizzawi, M. and Alnaser, F.M. (2019), “Integration of UTAUT model in internet banking adoption context: the mediating role of performance expectancy and effort expectancy”, *Journal of Research in Interactive Marketing*, Vol. 13 No. 3, pp. 411-435.

Rajahonka, M. and Villman, K. (2019), “Women managers and entrepreneurs and digitalization: on the verge of a new era or a nervous breakdown?”, *Technology Innovation Management Review*, Vol. 9 No. 6, p. 1246.

Ramaano, A.I. (2022a), “Musina municipality tourism management and strategies: a sustainable-eco-tourism inclusive business insights for the town, abbuting peri-urban and countryside existences”, *Management of Environmental Quality: An International Journal*, Vol. 33 No. 3, pp. 718-738.

Ramaano, A.I. (2022b), “The economic-administrative role of geographic information systems in rural tourism and exhaustive local community development in African marginalized communities”, *Arab Gulf Journal of Scientific Research*, Vol. 40 No. 2, pp. 180-195.

Ramaano, A.I. (2022c), “The implied significance of integrative geographical information systems in sustainable tourism and comprehensive community development in Musina Municipality, South Africa”, *Technological Sustainability*, Vol. 1 No. 1, pp. 42-63.

Ramaano, A.I. (2022d), “The potential role of cultural heritage resources in tourism and community development at Musina municipality, Limpopo province, South Africa”, *Journal of Cultural Heritage Management and Sustainable Development*, Vol. 14 No. 4.

Ramaano, A.I. (2023a), “Alternative ecotourism perspectives within the protected conservation sites and farming communities amid environmental degradation and climate change-bound rural exercises”, *Forestry Economics Review*, Vol. 5 No. 1, pp. 77-104.

Ramaano, A.I. (2023b), “Geographical information systems in sustainable rural tourism and local community empowerment: a natural resources management appraisal for musina municipality”, *Local Development and Society*, Vol. 4 No. 1, pp. 74-105.

Raman, A. (2016), “How do social media, mobility, analytics and cloud computing impact nonprofit organizations? A pluralistic study of information and communication technologies in indian context”, *Information Technology for Development*, Vol. 22 No. 3, pp. 400-421.

Sama, L.M., Stefanidis, A. and Casselman, R.M. (2021), “Rethinking governance for the digital era: the role of stewardship”, *Business Horizons*, Vol. 65 No. 5, pp. 535-546.

Schneider, S. and Kokshagina, O. (2021), “Digital transformation: what we have learned (thus far) and what is next”, *Creativity and Innovation Management*, Vol. 30 No. 2, pp. 384-411.

Schulz, D. and Newig, J. (2015), “Assessing online consultation in participatory governance: conceptual framework and a case study of a national sustainability-related consultation platform in Germany”, *Environmental Policy and Governance*, Vol. 25 No. 1, pp. 55-69.

Seele, P. (2016), “Envisioning the digital sustainability panopticon: a thought experiment of how big data may help advancing sustainability in the digital age”, *Sustainability Science*, Vol. 11 No. 5, pp. 845-854.

Senbekov, M., Saliev, T., Bukeyeva, Z., Almabayeva, A., Zhanaliyeva, M., Aitenova, N. and Fakhradiyev, I. (2020), “The recent progress and applications of digital technologies in healthcare: a review”, *International Journal of Telemedicine and Applications*, Vol. 2020, p. 8830200.

Setiawan, M., Effendi, N., Santoso, T., Dewi, V.I. and Sapulette, M.S. (2020), “Digital financial literacy, current behavior of saving and spending and its future foresight”, *Economics of Innovation and New Technology*, Vol. 31 No. 4, pp. 1-19.

Shah, S.S. and Shah, S.A.H. (2024), “Trust as a determinant of social welfare in the digital economy”, *Social Network Analysis Mining*, Vol. 14 No. 1, p. 79.

Singh, A. and Hess, T. (2020), “How chief digital officers promote the digital transformation of their companies”, *Strategic Information Management*, Routledge, Oxfordshire, England, pp. 202-220.

Singh, K., Goel, S. and Agrawal, A. (2016), “A review on SMAC: a new dimension to the business world”, *International Journal of Computer Applications*, Vol. 126 No. 6.

Singh, V.K., Singh, P., Karmakar, M., Leta, J. and Mayr, P. (2021), “The journal coverage of Web of Science, Scopus and dimensions: a comparative analysis”, *Scientometrics*, Vol. 126 No. 6, pp. 5113-5142.

Sparviero, S. and Ragnedda, M. (2021), “Towards digital sustainability: the long journey to the sustainable development goals 2030”, *Digital Policy, Regulation and Governance*, Vol. 23 No. 3, pp. 216-228.

Stratigea, A., Papadopoulou, C.-A. and Panagiotopoulou, M. (2015), "Tools and technologies for planning the development of smart cities", *Journal of Urban Technology*, Vol. 22 No. 2, pp. 43-62.

Sun, Z., Wang, W., Wang, W. and Sun, X. (2024), "How does digital transformation affect corporate social responsibility performance? From the dual perspective of internal drive and external governance", *Corporate Social Responsibility and Environmental Management*, Vol. 31 No. 2, pp. 1156-1176.

Sundberg, L. (2019), "Electronic government: towards e-democracy or democracy at risk?", *Safety Science*, Vol. 118, pp. 22-32, doi: 10.1016/j.ssci.2019.04.030.

Suseno, Y. and Abbott, L. (2021), "Women entrepreneurs' digital social innovation: linking gender, entrepreneurship, social innovation and information systems", *Information Systems Journal*, Vol. 31 No. 5, pp. 717-744.

Teece, D.J. (2007), "Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance", *Strategic Management Journal*, Vol. 28 No. 13, pp. 1319-1350.

Thapa, D., Sein, M.K. and Sæbø, Ø. (2012), "Building collective capabilities through ICT in a mountain region of Nepal: where social capital leads to collective action", *Information Technology for Development*, Vol. 18 No. 1, pp. 5-22.

Thorpe, A. and Lim, L.L. (2013), "'Technohesion': engaging students of higher education through digital technology and interactive marketing–a research agenda and theoretical framework", *European Journal of Higher Education*, Vol. 3 No. 4, pp. 357-370.

Tomor, Z., Meijer, A., Michels, A. and Geertman, S. (2019), "Smart governance for sustainable cities: findings from a systematic literature review", *Journal of Urban Technology*, Vol. 26 No. 4, pp. 3-27.

Tuyen, B.Q., Mai, N.P. and Long, T.Q. (2023), "Does corporate engagement in social responsibility affect firm innovation? The mediating role of digital transformation", *International Review of Economics and Finance*, Vol. 84, pp. 292-303.

Urbinati, A., Bogers, M., Chiesa, V. and Frattini, F. (2019), "Creating and capturing value from big data: a multiple-case study analysis of provider companies", *Technovation*, Vol. 84-85, pp. 21-36.

Urick, M. (2020), "Generational differences and COVID-19: positive interactions in virtual workplaces", *Journal of Intergenerational Relationships*, Vol. 18 No. 4, pp. 379-398.

Valenzuela, S. and Rojas, H. (2019), "Taming the digital information tide to promote equality", *Nature Human Behaviour*, Vol. 3 No. 11, pp. 1134-1136.

Van der Meer, T. and Tolsma, J. (2014), "Ethnic diversity and its effects on social cohesion", *Annual Review of Sociology*, Vol. 40 No. 1, pp. 459-478.

Van Zanten, J.A. and van Tulder, R. (2021), "Towards nexus-based governance: defining interactions between economic activities and sustainable development goals (SDGs)", *International Journal of Sustainable Development and World Ecology*, Vol. 28 No. 3, pp. 210-226.

Vial, G. (2019), "Understanding digital transformation: a review and a research agenda", *The Journal of Strategic Information Systems*, Vol. 28 No. 2, pp. 118-144.

Visser, M., van Eck, N.J. and Waltman, L. (2021), "Large-scale comparison of bibliographic data sources: Scopus, Web of Science, Dimensions, Crossref and Microsoft Academic", *Quantitative Science Studies*, Vol. 2 No. 1, pp. 20-41.

Wallace, C., Vincent, K., Luguzan, C., Townsend, L. and Beel, D. (2017), "Information technology and social cohesion: a tale of two villages", *Journal of Rural Studies*, Vol. 54, pp. 426-434.

Wang, Q. and Waltman, L. (2016), "Large-scale analysis of the accuracy of the journal classification systems of Web of Science and Scopus", *Journal of Informetrics*, Vol. 10 No. 2, pp. 347-364.

Weber, R., Braun, J. and Frank, M. (2022), “How does the adoption of digital technologies affect the social sustainability of small-scale agriculture in South-West Germany?”, *International Journal on Food System Dynamics*, Vol. 13 No. 3, pp. 275-293.

Weber-Lewerenz, B. and Vasiliu-Feltes, I. (2022), “Empowering digital innovation by diverse leadership in ICT–a roadmap to a better value system in computer algorithms”, *Humanistic Management Journal*, Vol. 7 No. 1, pp. 117-134.

Wilhelm, A.G. (2002), *Democracy in the Digital Age: Challenges to Political Life in Cyberspace*, Routledge, New York.

Xiao, D. and Su, J. (2022), “Role of technological innovation in achieving social and environmental sustainability: mediating roles of organizational innovation and digital entrepreneurship”, *Frontiers in Public Health*, Vol. 10, p. 850172.

Xu, C., Zhao, W., Li, X., Cheng, B. and Zhang, M. (2024), “Quality of life and carbon emissions reduction: does digital economy play an influential role?”, *Climate Policy*, Vol. 24 No. 3, pp. 346-361.

Yang, Y. and Han, J. (2023), “Digital transformation, financing constraints, and corporate environmental, social, and governance performance”, *Corporate Social Responsibility and Environmental Management*, Vol. 30 No. 6, pp. 3189-3202.

Yang, L. and Walker, R. (2021), “Village governance, social cohesion and contentment with social assistance in Northern China”, *Journal of Asian Public Policy*, Vol. 16 No. 2, pp. 1-17.

Yang, P., Hao, X., Wang, L., Zhang, S. and Yang, L. (2024), “Moving toward sustainable development: the influence of digital transformation on corporate ESG performance”, *Kybernetes*, Vol. 53 No. 2, pp. 669-687.

Yaqub, M.Z. and Alsabban, A. (2023), “Industry-4.0-enabled digital transformation: prospects, instruments, challenges, and implications for business strategies”, *Sustainability*, Vol. 15 No. 11, p. 8553.

Youssef, A.E. (2012), “Exploring cloud computing services and applications”, *Journal of Emerging Trends in Computing and Information Sciences*, Vol. 3 No. 6, pp. 838-847.

Yuen, K.F., Koh, L.Y., Fong, J.H. and Wang, X. (2024), “Determinants of digital transformation in container shipping lines: a theory-driven approach”, *Maritime Policy and Management*, Vol. 51 No. 5, pp. 653-668.

Zheng, Y. and Zhang, Q. (2023), “Digital transformation, corporate social responsibility and green technology innovation-based on empirical evidence of listed companies in China”, *Journal of Cleaner Production*, Vol. 424, p. 138805.

Ziadlou, D. (2021), “Strategies during digital transformation to make progress in achievement of sustainable development by 2030”, *Leadership in Health Services*, Vol. 34 No. 4, pp. 375-391.

Ziemba, E. (2019), “The contribution of ICT adoption to the sustainable information society”, *Journal of Computer Information Systems*, Vol. 59 No. 2, pp. 116-126.

Zissis, D. and Lekkas, D. (2012), “Addressing cloud computing security issues”, *Future Generation Computer Systems*, Vol. 28 No. 3, pp. 583-592.

Zou, Y. and Zhao, W. (2021), “Neighbourhood governance during the COVID-19 lockdown in Hangzhou: coproduction based on digital technologies”, *Public Management Review*, Vol. 24 No. 12, pp. 1-19.

**Further reading**

Barykin, S.E., Sergeev, S.M., Kapustina, I.V., Fedotov, A.A., Matchinov, V.A., Plaza, E.D.L.P. and Karmanova, A.E. (2023), “Environmental sustainability and digital transformation of socio-economic: quality of life perspective”, *Journal of Environmental Assessment Policy Management Decision*, Vol. 25 No. 1, p. 2350001.

Feroz, A., Zo, H. and Chiravuri, A. (2021), “Digital transformation and environmental sustainability: a review and research agenda”, *Sustainability*, Vol. 13 No. 3, p. 1530.

Jones, M.L. (2004), “Application of systematic review methods to qualitative research: practical issues”, *Journal of Advanced Nursing*, Vol. 48 No. 3, pp. 271-278.

Moher, D., Liberati, A., Tetzlaff, J. and Altman, D.G. (2010), “Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement”, *International Journal of Surgery*, Vol. 8 No. 5, pp. 336-341.

Staples, M. and Niazi, M. (2007), “Experiences using systematic review guidelines”, *Journal of Systems and Software*, Vol. 80 No. 9, pp. 1425-1437.

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# Evolution and impact of the science of science: from theoretical analysis to digital-AI driven research

Jianhua Hou [1]✉, Bili Zheng[1], Hao Li[1] & Wenjing Li[1]

The Science of Science (SoS) examines the mechanisms driving the development and societal role of science, evolving from its sociological roots into a data-driven discipline. This paper traces the progression of SoS from its early focus on the social functions of science to the current era, characterized by large-scale quantitative analysis and AI-driven methodologies. Scientometrics, a key branch of SoS, has utilized statistical methods and citation analysis to understand scientific growth and knowledge diffusion. With the rise of big data and complex network theory, SoS has transitioned toward more refined analyses, leveraging artificial intelligence (AI) for predictive modeling, sentiment annotation, and entity extraction. This paper explores the application of AI in SoS, highlighting its role as a surrogate, quant, and arbiter in advancing data processing, data analysis and peer review. The integration of AI has ushered in a new paradigm for SoS, enhancing its predictive accuracy and providing deeper insights into the internal dynamics of science and its impact on society.

## Introduction

Since its creation, the Science of Science (SoS), which takes science as a whole as its object of study, has always been closely linked with the development and evolution of science and technology (S&T), and has taken the study of the laws of science's development and its social functions as the core of its disciplinary evolution. The development of S&T has promoted the transformation of SoS's research paradigm. At present, the latest scientific and technological revolutions and industrial transformations are on the way, digital intelligence-driven scientific discoveries and scientific research paradigm transformation promote scientific development to step into the intelligent era. Moreover, "AI for Science" fully integrated into scientific research, decision-making, scientific management (governance), development strategy and other aspects. SoS witnesses unprecedented significant development opportunities and challenges.

The evolution of SoS has been significantly influenced by shifts in scientific research paradigms, tracing its roots back to philosophical and scientific thought before SoS was formally established. The spotlight on science's role in societal development and human progress, especially noted in the early 20th century, paved the way for SoS's formal inception. In 1925, Polish sociologist F. Znaniecki advocated for a "science of science," laying foundational ideas for SoS. A pivotal moment came in 1931 when the former Soviet delegate N. Bukhari, at the Second

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International Conference on the History of Science in London, presented Boris Hessen's report on Newton's "Principia" linking Newtonian mechanics to social contexts, which is considered a landmark exploration in SoS. The 1939 publication "*The Social Function of Science*" by British physicist J. D. Bernal further established SoS, emphasizing the analysis of the connection between science and society. By the 1960s, the emergence of scientometrics shifted SoS from sociological analysis to a quantitative phase, leading to its maturity. This conventional phase of SoS has since fostered the growth of related fields such as S&T management, innovation, and policy.

In the 21st century, the emergence of data-driven scientific research has rejuvenated the Study of SoS, with "AI for Science" leading the charge into new research paradigms. This shift has sparked a greater emphasis on conducting research over understanding the deeper nuances of science itself, making the scientific process and knowledge system increasingly complex. This complexity demands a more profound understanding and explanation of science, facilitated by the advent of large-scale data, advanced computing, and precise algorithms, which significantly enhance our ability to explain scientific phenomena. Consequently, SoS is poised to evolve into a more integrated discipline, signaling its maturity and underscoring the need for a new, modern framework for SoS (Kuhn, 1962); (Shneider, 2009).

The paper delves into the evolution and history of the Study of SoS, emphasizing its pivotal role in blending science, technology, and society. By systematically examining the SoS's growth, the paper aims to highlight how SoS has been crucial in linking and advancing both the natural and social sciences. It acknowledges and interprets the importance of science in societal roles, offering theoretical and practical frameworks to better grasp the intricate relationship between science, technology, and society. This approach aims to enrich our understanding of science by exploring the dynamic interactions among these fields.

## The social function of science: Sociological research on SoS

Since the 19th century, S&T have become increasingly intertwined, forming an indissoluble bond. Unresolved scientific questions often lead to technological innovations, while scientific endeavors rely on technological advancements for experimental tools and methods. This interplay has deeply influenced modern society, which now fundamentally rests on the pillars of contemporary S&T. The impact of natural sciences on society has, in turn, become a focus of social sciences, with their methods and theories providing critical insights and approaches in social scientific inquiry. The concept of scientific labor's socialization has also entered academic discourse, highlighted by Hessen's (1931) exploration of the social and economic influences on Newton's "Principia" and Merton's works, such as "*Science, Technology, and Society in Seventeenth-Century England*" (Merton, 1973) and "*Social Theory and Social Structure*" (Merton, 1973), marking the advent of a sociological lens in science studies.

In the early 20th century, the field of 'science studies' began to take shape, notably with Polish sociologist Florian Witold Znaniecki coining the term in his 1925 article "The Object and Tasks of the Science of Knowledge." The following year, N. Richevsky from the former Soviet Union expanded the concept to include the societal impacts of science. Further clarity and terminology, 'science of science' were introduced by Tadeusz Kotarbinski in 1929, and by Polish sociologists, the Ossowskis, in 1935, broadening the research scope within this emerging field. A landmark moment came with Boris Hessen's 1931 presentation in London, focusing on the social factors influencing natural science, highlighting the field's importance. American sociologist Robert King Merton, influenced by Hessen, delved into the science-society relationship in 17th-century England, adopting a sociological approach. Merton's identification of the 'Matthew effect' played a crucial role in establishing the sociology of science and science studies, significantly advancing our understanding of the dynamics between science and societal structures.

In 1939, the British scientist J.D. Bernal, in his book "*The Social Function of Science*", presented for the first time a comprehensive and extensive proposal to study the entire realm of scientific issues using the historical and sociological methods of natural science. Simultaneously, he advocated the integration of qualitative and quantitative research methods, aiming to conduct a comprehensive examination of the significant social phenomenon of "science" within the broader societal framework (Bernal 1939). This groundbreaking approach gave rise to a novel discipline known as the SoS. Upon its publication, this book swiftly became the foundational theoretical work in the field of SoS. Furthermore, Bernal authored numerous works that encapsulated the scientific achievements of his time, revealing the philosophical significance of science and its role in human history. His writings also addressed the contradictions in the development of science within class societies and the continuous progress of science under socialist systems. Due to Bernal's prominent contributions to the study of the SoS, he is acknowledged in academia as the founder of the discipline of SoS.

Since the 1960s, the study of SoS has evolved to encompass a range of research methods and theories, introducing new dimensions of analysis. The historical dimension focuses on and examines the historical processes of scientific development, the evolution of scientific thought, as well as the formation and changes in scientific paradigms. In addition, one key area, scientometrics, focusing on the quantitative analysis of science, has since become a central discipline within SoS, revitalizing the field with its focus on measuring and understanding scientific output and influence.

## From qualitative analysis to large-scale quantitative analysis: Scientometrics as a branch of SoS

The established research paradigm within SoS has traditionally hinged on the compilation of past experiences and the construction of speculative theories, thereby securing its academic standing and theoretical foundation. Nevertheless, the rapid progress in S&T has posed substantial challenges to this conventional approach. In the era of "big science," the exponential expansion of scientific knowledge necessitates that the SoS discipline refine its ability to pinpoint the leading edge of scientific and technological advancements, disclose the underlying forces driving scientific progress, and furnish actionable insights for societal utility. The adoption of quantitative analysis methods that are both calculable and interpretable, grounded in the field's extant theories, hypotheses, and models, is of paramount importance.

**Statistical analysis of the laws of scientific development**. The field of science studies, often traced back to the 1920s or 1930s, actually began in the late 19th century with natural scientists collecting statistical data on peers using mathematical statistical methods. Victorian naturalist Sir Francis Galton (1822–1911) was pivotal, in identifying the 'regression toward the mean' phenomenon (Galton, 1886) and introducing the correlation coefficient (Lee Rodgers & Nicewander, 1988). He analyzed traits of British scientists in '*English Men of Science: Their Nature and Nurture*' using questionnaires (Galton, 1874). Inspired by Galton, James McKeen Cattell evaluated American scientists' productivity based on peer review (Cattell, 1906).

Scientific literature became a focus of quantitative research. Alfred James Lotka (1880–1949) proposed Lotka's law, stating that the number of authors who have written n papers is approximately $1/n^2$ of the number of authors who have written 1 paper (Lotka, 1926). Other milestones include Zipf's Law and Bradford's Law, revealing the distribution of word frequency in English literature (Kingsley Zipf, 1932) and the dispersion/concentration of scientific literature in journals (Bradford, 1934).

Early studies had limited understanding of science due to a lack of theoretical guidance. Galton proposed 'genius is hereditary' in '*Hereditary Genius*', and Lotka focused on the applicability of Lotka's law (Galton, 1891). However, these studies impacted SoS development, highlighting the value of quantitative methods. John D. Bernal (1901–1971), the founder of SoS, used data charts in '*The Social Function of Science*' to analyze government funding, teaching staff income, and scientist numbers (Bernal, 1939).

With the growth of scientific literature, establishing a quantitative research paradigm for SoS was crucial. Derek J. de Solla Price (1922–1983), influenced by Bernal, shifted from physics/mathematics to SoS. He identified the exponential growth of scientific literature, known as the Price Index (De Solla Price, 1975). Price's works '*Science since Babylon*' and '*Little Science, Big Science*' organized and developed the research of Galton, Lotka, Bradford, and Zipf, proposing Price's Law, a further deduction of Lotka's law (D. J. D. S. Price, 1963). These works laid the foundation for quantitative research in SoS, attracting global interest.

**Citation analysis and visualization in scientific knowledge networks**. The development of SoS relies on scientific statistical data. American information scientist Eugene Eli Garfield (1925-2017) made significant contributions to this field by proposing in 1955 the use of citation relationships between scientific literature to analyze the dynamics and structure of scientific development (Garfield, 1955). This pivotal concept laid the groundwork for the subsequent establishment of databases like the Science Citation Index (SCI), Social Science Citation Index (SSCI), Journal Citation Report (JCR), and Arts and Humanities Citation Index (A&HCI), which collectively gather citation data from nearly 180 fields of books and journal articles. Garfield's work not only provided a substantial data foundation for the quantitative research paradigm of SoS but also introduced new theories and methods, namely citation analysis, which greatly expanded the potential for SoS research development.

Citation frequency and its derived indicators, such as the h-index (Hirsch, 2005), have been widely adopted to quantify concepts like academic influence, scientific productivity, and labor efficiency. Garfield's early work analyzing citation frequency identified patterns such as the correlation between rapid citation and Nobel Prize nominations (Garfield & Malin, 1968). The citation frequency has been a crucial tool for measuring the status and influence of American science (Board, 1981). Vasiliy Vasilevich Nalimov (1910-1997), the inventor of the term 'scientometrics' in the Soviet Union, emphasized the importance of citation rate over publication count for measuring scientific productivity (Granovsky, 2001).

Moreover, the distribution of citations over time has drawn attention, with scholars studying literature aging through citation curves. Bernal's concept of "literature half-life" in 1958 (Xiao, 2011) and Price's "Price index" (D. d. S. Price, 1976) in 1976 were key developments in quantifying literature aging. The "Sleeping Beauty in Science" phenomenon, identified by van Raan (Van Raan, 2004), refers to papers initially ignored that later received a surge in citations, which has attracted wide attention in SoS.

Citation relationships are used to construct networks to study the structure and evolution of scientific knowledge diffusion and cooperation. Price was the first scholar who discovered the phenomenon of 'advantage accumulation' in the growth of citation networks and gave a mathematical explanation for the evolution of citation networks (D. d. S. Price, 1976). The subsequent development of coupling analysis (Kessler 1963), co-citation (H. Small, 1973), co-authorship (Glänzel & Schubert, 2004), keyword co-occurrence (Callon, Courtial, & Laville, 1991), and reference co-occurrence (Porter & Chubin, 1985) have provided deeper insights into the dynamics of scientific knowledge. Social network analysis has further enriched the toolkit of scientometrics (Egghe & Rousseau, 1990).

Theoretical foundations for applying citation analysis to scientometrics have been established, considering citation motivation (Garfield, 1965) and information systems. Nalimov's cybernetic model of science (Nalimov & Mul'chenko, 1969) and Merton's sociological theories of citation (Merton, 1973) have contributed to understanding the role of citations in scientific evaluation (H. G. Small, 1978).

The paradigm shift from mathematical expression to visual representation in scientometrics has been facilitated by the introduction of information visualization techniques. Tools like CiteSpace (Chen, 2006), HistCite (Garfield, 2006), BibExcel (Persson, Danell, & Schneider, 2009), Vosviewer (N. Van Eck & Waltman, 2010), and CitnetExplorer (N. J. Van Eck & Waltman, 2014) have allowed for the visualization of citation networks, knowledge domains, and other complex data structures. This shift has led to the emergence of mapping knowledge domains as a new quantitative research field in SoS, enabling a more intuitive and comprehensive understanding of scientific knowledge networks and their evolution.

**Large-scale and fine-grained shifts in SoS: leveraging big data and complex network**. The evolution of SoS has witnessed a transformative shift towards large-scale and fine-grained analysis, driven by the emergence of big data and the application of complex network theory. This shift has been enabled by the accessibility of diverse data sources and the utilization of advanced computational tools, which have expanded the scope and depth of SoS research.

The availability of a wide range of data types, from social media to clinical trial records, has provided SoS researchers with a rich and interconnected dataset, such as OpenAlex, Publons, Dimensions, Semantic Scholar, Microsoft Academic Graph and so on. The opening of SciScinet in 2023, with its vast collection of over 134 million scientific documents and associated records, represents a significant leap in data availability and connectivity. This data deluge has not only increased the scale of SoS research but also facilitated more nuanced analyses (Z. Lin, Yin, Liu, & Wang, 2023). For instance, the study of the interaction between scientific papers and policies has become possible by constructing citation relationships between these two domains, revealing the integration of scientific research and policy-making (Yin, Gao, Jones, & Wang, 2021).

The scale of data in SoS research has exploded, enabling cross-validation of complex scientific problems and societal challenges. Research on scientists' career dynamics (Huang, Gates, Sinatra, & Barabási, 2020; Wang, Jones, & Wang, 2019), collaboration patterns (Bu, Ding, Liang, & Murray, 2018; Bu, Murray, Ding, Huang, & Zhao, 2018; Wu, Wang, & Evans, 2019), and the evolution of science (Gates, Ke, Varol, & Barabási, 2019) itself have been enriched by the analysis of millions of scientific papers, grants, and mobility data. This scale has allowed for the exploration of subtle differences in career trajectories, collaboration dynamics, and disciplinary trends.

The introduction of complex networks has driven a shift towards more refined SoS research. These networks, characterized by self-organization, self-similarity, and scale-free properties, offer new perspectives on the dynamic processes, complex relationships, and underlying mechanisms of scientific development. Complex networks provide interpretability to the dynamic evolution of citation networks (Fortunato et al., 2018; Parolo et al., 2015), recognition of the intricate relationships between knowledge creation and diffusion (Sankar, Thumba, Ramamohan, Chandra, & Satheesh Kumar, 2020; X.-h. Zhang et al., 2019), and inference of the mechanisms driving scientific activities (Jia, Wang, & Szymanski, 2017; A. Zeng et al., 2019).

The field of complex networks has attracted notable scholars, leading to the emergence of a new paradigm in SoS research after 2010. However, this reliance on model characterization and interpretation has also led to the "trap of numbers," (Sugimoto, 2021) highlighting the need for a balanced approach that combines quantitative data with qualitative insights to fully understand the complexities of SoS research.

### From scientometrics to AI-driven research: The latest Paradigm of SoS

Since 2010, the development of scientific data infrastructures and the rise of artificial intelligence (AI) large models have led to a qualitative leap in SoS, both in terms of data sources and scale. The future of SoS lies in expanding its scope, particularly by incorporating more diverse methodologies and data sources ("Broader scope is key to the future of 'science of science'," 2022). This shift is crucial for addressing long-standing issues such as data scarcity, methodological limitations, and biases within the scientific community. In recent years, the ongoing global scientific and technological revolution, driven by digital intelligence and big data, has profoundly impacted traditional scientific research activities. This paradigm shift, characterized by "AI for science," leverages massive datasets to learn scientific laws and natural principles, offering cutting-edge tools for advancing research (X. Zhang et al., 2023). AI plays a pivotal role in this transformation, acting as both a surrogate and a quant to enhance data collection, curation, and analysis (Messeri & Crockett, 2024), thereby improving the efficiency and scalability of SoS research. This evolution is propelling significant progress in SoS research and reshaping the landscape of scientific inquiry.

**AI as Surrogate in SoS**. In the face of complex research questions and the deluge of data collection and integration, AI serves as a powerful surrogate for scientometrics. It excels in processing vast amounts of data and generating alternative datasets, thereby reducing the burden on human researchers and enhancing the efficiency of data collection. Machine learning, deep learning and other artificial intelligence technologies address multi-dimensional, multi-modal, and multi-scenario data collection and simulation, assist researchers in a large number of experiments for verification (Peng et al., 2023), solve complex computing, and accelerate the pace of scientific research and technology development. For example, AI plays a vital role in sentiment annotation and entity extraction.

*AI in sentiment annotation*. Sentiment annotation is one of the most significant applications of AI in SoS. For instance, AI algorithms can analyze textual and audiovisual data from scientific publications, conference presentations, and online discussions to automatically label sentiments expressed by researchers. This not only streamlines the time-consuming process of manual annotation but also enables the detection of nuanced emotional trends within the scientific community that might otherwise be overlooked. Citation sentiment classification differs from general sentiment annotation tasks. While the latter focuses on semantic emotions in text (e.g., positive/negative/neutral), citation sentiment specifically refers to the stance (agreement, disagreement, or neutrality) that authors hold toward the cited work.

(1) Methods for sentiment annotation

Methods for sentiment analysis using artificial intelligence encompass rule-based approaches, supervised learning, semi-supervised learning, and unsupervised learning. These methods utilize predefined rules and dictionaries to identify sentiment words and phrases within a text, allowing for the judgment of the text's sentiment. For example, a dictionary containing positive and negative words can be used to determine the sentiment of a text based on the frequency of these words. Supervised learning involves training a model to recognize sentiment words within a text and learn how to classify the text's sentiment as positive, negative, or neutral. For instance, a large dataset of labeled text (i.e., text with known sentiment) can be used to train a classification model, such as a support vector machine (SVM) or a naive Bayes classifier, to predict the sentiment of new, unseen text. Semi-supervised learning leverages a small amount of labeled data and a large amount of unlabeled data. The model automatically labels the unlabeled data and then further trains itself using this newly labeled data. This approach is useful when labeled data is scarce and expensive to obtain. Unsupervised learning identifies sentiment patterns within a text, such as the co-occurrence of words, to infer the sentiment. For example, clustering algorithms can group similar texts based on their sentiment, allowing for the identification of different sentiment categories within a dataset.

(2) Sentiment annotation in SoS

AI has been successfully applied in analyzing the stance and sentiment within academic papers and reports to assess their scientific value and influence. For instance, citation sentiment analysis can evaluate how researchers view the contributions of cited documents—whether with agreement, disagreement, or neutrality—rather than only capturing the general semantic sentiment within the text. Using such methods, the stance in citations can be divided into positive (based on; corroboration; discovery; positive; practical; significant; standard; supply), neutral (contrast; co-citation; neutral), and negative (Aljuaid, Iftikhar, Ahmad, Asif, & Tanvir Afzal, 2021; Budi & Yaniasih, 2023; Kong et al., 2024). This distinction emphasizes that citation sentiment analysis is not just a subset of general sentiment classification, but a specialized task for academic discourse, providing a methodological foundation for the validation of classic SoS theoretical models such as social constructivist theory (Gilbert, 1977) and normative theory (Merton, 1973).

Moreover, with the rise of the "Public Understanding of Science" movement, the introduction of sentiment analysis methods helps the research of SoS to expand its research objects from the scientific community to the general public. This enables SoS to be more applicable to addressing issues regarding the relationship between modern society and science. AI-driven sentiment analysis can help policymakers identify and predict public opinions, providing essential support for decision-making processes. By analyzing large volumes of data from social media platforms and public reports, AI can track the emotional responses of different segments of the population toward scientific policies or projects. For example, during the COVID-19 pandemic, sentiment analysis of social media revealed key public concerns and emotional reactions, which could inform public health authorities on how to adjust their communication strategies to address fear and misinformation more effectively (Li et al., 2023). Besides, AI-driven sentiment analysis allows for the identification of emerging concerns that might not be immediately visible through traditional surveys or reports. This real-time analysis provides decision-makers with valuable insights to anticipate potential backlash or support for upcoming policies (Xue et al., 2020).

*AI in entity extraction and annotation*. Another illustrative example lies in the realm of entity extraction and annotation. AI tools can swiftly identify and classify key entities such as researchers, institutions, funding agencies, and research topics within vast corpora of scientific literature. This automation facilitates the construction of complex knowledge graphs, revealing intricate relationships and patterns that would be challenging to uncover manually.

Observation units are intelligently extracted from macro-units to micro-units of knowledge. In the past, scientific knowledge units are generally based on papers, patents, journals, or disciplines, and thus the research on scientific development in SoS is limited to macro-knowledge units (Y. Liu & Rousseau, 2010). Since the LDA was proposed in 2002, the efficiency of scientific or technical knowledge unit extraction based on scientific papers and patent texts has been greatly improved. After 2013, Large Language models (LLMs) such as Word2Vec, Top2Vec, and BERT, GPT which have powerful contextual understanding, language generation, and learning capabilities, optimize the analysis and annotation of full text, semantic recognition and prediction, strengthen the topic extraction efficiency and characterization ability of scientific text and technical text (Reimers & Gurevych, 2019), and promote the SoS's research to explore the science from the fine-grained perspective. In SoS, AI-based entity extraction techniques have been applied to various tasks, advancing research in scientific knowledge mapping, bibliometric analysis, and the construction of knowledge graphs.

Researcher and institution identification: AI entity extraction techniques, such as those implemented in Sentence-BERT (Reimers & Gurevych, 2019) and SciSpaCy (Neumann, King, Beltagy, & Ammar, 2019), have been used to automatically identify and classify researchers, institutions, and research topics from vast corpora of academic papers and patents. This has facilitated the construction of large-scale knowledge graphs, which reveal the relationships and collaborations between different entities in scientific ecosystems. These graphs are then used to study collaboration networks, innovation patterns, and the evolution of research domains.

Patent and citation analysis: AI-based entity extraction models, such as BERT (Devlin, Chang, Lee, & Toutanova, 2018) and Word2Vec (Mikolov, Chen, Corrado, & Dean, 2013), are commonly employed in patent and citation databases to extract key entities like inventors, patents, journals, and disciplines. This allows researchers to analyze citation trends, measure scientific influence, and explore how knowledge flows between disciplines through patents and scholarly work.

Construction of fine-grained knowledge units: Since the introduction of models like LDA (Blei, Ng, & Jordan, 2003), and later enhanced by BERT-based models, entity extraction has been crucial for extracting fine-grained knowledge units from scientific texts. These models have improved the ability to identify technical terms, research outcomes, and domain-specific entities at a more granular level, advancing the study of micro-units of knowledge in SoS. Moreover, models specifically fine-tuned for scientific documents, such as SciBERT (Beltagy, Lo, & Cohan, 2019), SPECTER (Cohan, Feldman, Beltagy, Downey, & Weld, 2020), and SPECTER2 (Singh, D'Arcy, Cohan, Downey, & Feldman, 2022), have achieved high performance in tasks closely related to SoS. SciBERT significantly enhances the extraction and interpretation of scientific terms and named entities, making it highly effective for domain-specific knowledge tasks. SPECTER and SPECTER2, designed for document-level representation using citation-informed transformers, are particularly adept at capturing relationships between scientific documents based on citation networks, aiding in the construction of accurate, large-scale knowledge graphs that reveal complex interconnections within scientific research.

Biomedical and clinical research: In the context of biomedical research, entity extraction tools like Med7 (Kormilitzin, Vaci, Liu, & Nevado-Holgado, 2021) have been utilized to extract clinical entities (e.g., diseases, treatments) from scientific publications and electronic health records. These extracted entities are used to map scientific advancements in medicine, track the development of treatments, and understand trends in healthcare innovation.

*AI in image recognition*. AI has significantly advanced the detection of image-related issues in scientific publishing, particularly in biomedical research, ensuring data integrity and ethical compliance. Convolutional Neural Networks (CNNs), such as AlexNet, GoogleNet, ResNet, R-CNN and FCNN models are widely used to identify duplicated or manipulated images by analyzing features like contrast, brightness, and structural patterns (Yu, Yang, Zhang, Armstrong, & Deen, 2021). Similarly, Generative Adversarial Networks (GANs) and anomaly detection models are applied to recognize subtle image manipulations, such as artificial enhancements or duplicated sections, potentially leading to research misinterpretation (X. Liu et al., 2021). Further, algorithm like PCA (Plehiers et al., 2020), t-SNE (Schubert & Gertz, 2017), DBSCAN (Çelik, Dadaşer-Çelik, & Dokuz, 2011) or LSTM (Fernando, Denman, Sridharan, & Fookes, 2018) are usually used for anomaly detection, which ensured data authenticity in biomedical datasets. Additionally, Imagetwin (https://imagetwin.ai/) and Proofig (https://www.proofig.com/), are examples of tools that utilize AI to detect potential image anomalies, offering support to journals, publishers, and institutions in maintaining research integrity. In summary, the integration of AI in detecting image-related issues has become a powerful tool in SoS, reinforcing the accuracy and ethical standards of scientific research. Through advanced image recognition models and dedicated software, researchers and publishers are better equipped to monitor and verify visual data, contributing to the trustworthiness and quality of scientific knowledge.

**AI as quant in SoS**. AI's prowess in computational methods significantly supplements human capabilities, particularly when dealing with immense datasets and intricate relationships. It bridges the gap between human limitations and the demands of SoS research, enhancing both predictability and interpretability.

*Predictive algorithms*. AI has become an influential tool in predicting various aspects of scientific careers, research team performance, and research project outcomes. By utilizing machine learning algorithms and data analytics, AI provides insights that were previously difficult or impossible to obtain through traditional methods.

Predicting citation performance and citing behavior: AI applications in citing behavior research involve analyzing citation patterns through machine learning (T. Zeng & Acuna, 2020)and natural language processing to uncover insights about scholarly communication. By utilizing algorithms such as neural networks and regression models, researchers can predict citation counts based on various factors, including publication attributes and author influence (Akella, Alhoori, Kondamudi, Freeman, & Zhou, 2021). Studies have shown that these models can effectively identify biases in citation practices and the impact of collaboration on citation dynamics (Iqbal et al., 2021). Such insights enhance our understanding of knowledge dissemination and the complex networks that shape academic impact.

Predicting scientists' career trajectories: AI can model and predict the career patterns of scientists by analyzing their publications, citations, collaborations, and affiliations. Predictive algorithms such as decision trees, support vector machines (SVMs), and neural networks are employed to identify key factors influencing scientific productivity and career progression (Edwards, Acheson-Field, Rennane, & Zaber, 2023; Musso, Hernández, & Cascallar, 2020; Yang, Chawla, & Uzzi, 2019). For example, factors like the number of publications, the diversity of collaborations, and funding history can be fed into these algorithms to forecast future career success or the likelihood of achieving high-impact research outcomes (L. Liu, Dehmamy, Chown, Giles, & Wang, 2021; L. Liu et al., 2018; Wang et al., 2019).

Predicting research team performance: AI also plays a crucial role in evaluating and predicting the performance of research teams. By analyzing team composition, collaboration patterns, and historical project outcomes, predictive models can estimate the future productivity and success of a research team (Ghawi, Müller, & Pfeffer, 2021; Giannakas, Troussas, Krouska, Sgouropoulou, & Voyiatzis, 2022). Factors such as team size, team hierarchy, team distance, diversity in expertise, and the centrality of team members within their academic networks have been shown to correlate with team performance (Y. Lin, Frey, & Wu, 2023; Wu et al., 2019; Xu, Wu, & Evans, 2022).

Predicting research project outcomes: AI can significantly enhance the prediction of research project performance by analyzing multiple dimensions of project execution and outcomes. Through machine learning and data-driven models, AI can evaluate project success across various performance indicators, such as time management, resource allocation, collaboration dynamics, and the achievement of project goals (Yoo, Jung, & Jun, 2023). AI-powered predictive models often rely on historical data, such as past project performance, team expertise, funding amounts, and institutional resources, to make projections. These models can identify trends and patterns that forecast whether a project is likely to meet its objectives. The use of AI in predictive analytics offers insights into several key performance areas: timeline and milestones (Kim & Jang, 2024), budget and resource allocation (Jiang, Fan, Zhang, & Zhu, 2023), innovation and output (Gao, Wen, & Deng, 2022), team collaboration and productivity (Tohalino & Amancio, 2022; Yoo et al., 2023).

*Machine learning for explainability*. The construction of relationships in SoS spans from the investigation of extrinsic connections to the elucidation of intrinsic mechanisms. Examining the interconnections between elements within a scientific system has consistently been a pivotal aspect of SoS. During the sociological analysis phase, scientific inquiry typically employs deductive reasoning to establish relationships among elements. Regression and correlation analyses are frequently utilized to decipher the associations between elements in the realm of scientometrics. Since 2010, SoS research has leveraged causal inference models from econometrics, such as Difference in Differences, Regression Discontinuity Design, Granger Causality Test, Propensity Score Matching, and Instrumental Variables (Zhao et al., 2020), along with machine learning approaches like BART (Prado, Moral, & Parnell, 2021), TMLE (Schuler & Rose, 2017), and causal forest models (Wager & Athey, 2018) to delve into intrinsic causal mechanisms.

Machine learning methods play a crucial role in addressing the causal inference demands of large-scale and high-dimensional data. These methods are adept at processing extensive datasets, predicting nonlinear and complex relationships between causes and effects, and enhancing the precision of causal inferences. Furthermore, languages such as Python and R offer a plethora of causal inference packages, including Random Forest, XGBoost, and Super Learner, which facilitate intelligent inference of the intrinsic mechanisms governing scientific system elements within SoS research (Athey, Tibshirani, & Wager, 2019; Hill, Linero, & Murray, 2020). The application of machine learning-based causal inference is instrumental in unraveling the intricacies of complex relationships, providing deeper insights and more accurate predictions in the field of SoS research.

**AI as arbiter in SoS**. AI plays a significant role in the peer review process within SoS, offering the potential to enhance efficiency, reduce bias, and improve transparency. Generally speaking, the role of AI as an arbiter in peer review can be categorized into four types.

Automation of routine tasks: AI can automate many routine aspects of peer review, such as format checks, plagiarism detection, and manuscript matching. For example, tools like iThenticate help in detecting plagiarism, and Penelope.ai checks manuscript formatting (Kankanhalli, 2024). This helps to speed up the process and reduces the workload of human reviewers, allowing them to focus on more complex tasks like evaluating scientific rigor and originality. Similarly, StatReviewer and Statcheck assist with checking the statistical methods reported in papers (Nuijten & Polanin, 2020; Shanahan, 2016).

Reviewer-manuscript matching: AI tools, such as the Toronto Paper Matching System (TPMS), use machine learning algorithms to match reviewers with appropriate expertise to manuscripts (Charlin & Zemel, 2013). This process is more efficient than traditional keyword-based matching and ensures that the most suitable reviewers are selected (Kalmukov, 2020). Similarly, machine learning models have been employed by large conferences like NeurIPS to improve the accuracy of reviewer-paper matching (Kankanhalli, 2024; S. Price & Flach, 2017). By improving the quality of reviewer selection, AI helps to increase the quality and relevance of peer review feedback.

Bias mitigation: AI has the potential to reduce biases that are inherent in human peer review. Human reviewers may unintentionally introduce biases based on the author's institution, country, or research field (Thelwall & Kousha, 2023). AI systems trained on diverse datasets can mitigate some of these biases by evaluating manuscripts based on objective criteria like novelty or methodological soundness. Recent studies have shown that AI-based tools can help assess articles more objectively, although there remain challenges in fully eliminating biases from AI algorithms (Checco, Bracciale, Loreti, Pinfield, & Bianchi, 2021).

Challenges and ethical concerns: Despite its benefits, AI in peer review also introduces concerns, particularly related to transparency and algorithmic bias. AI algorithms, especially those based on deep learning, are often "black boxes," making it difficult for users to understand how decisions are made (Thelwall & Kousha, 2023). This raises concerns about fairness and accountability in the peer review process. Recent work has called for the development of more explainable AI models to enhance the transparency of decisions made by these systems (A & R, 2023; Vilone & Longo, 2020).

## Conclusion and future work

Since the beginning of the 20th century, when the term "science of science" was introduced in Poland, SoS has witnessed over 100 years of development. From qualitative analyses of science's social functions to large-scale quantitative approaches, such as scientometrics, the field has matured through the use of statistical methods, citation analysis, and big data. AI's role in SoS, acting as a surrogate for data processing, a quant for data analysis, and an arbiter for peer review, marks a transformative moment in the discipline. By integrating AI into SoS, researchers can analyze vast datasets with greater precision, predict project performance, and derive actionable insights into scientific productivity and collaboration. Moving forward, AI's capabilities will continue to reshape SoS, offering new opportunities to understand the dynamics of science and address societal challenges.

Looking into the future, after several research paradigm shifts and enlightenment, SoS's research will open a new era of AI for SoS, facing the strategic needs and practical problems of scientific development, focusing on the political, economic, cultural, societal and other dimensions of science. First of all, it is necessary to strengthen the sense of disciplinary community in SoS, enhance the construction of disciplinary infrastructure, and cohesion of disciplinary core strength. Secondly, SoS's research must be based on the "problem-oriented" items, especially those related to sustainable development and scientific governance. Lastly, researchers should go out of the "ivory tower" to convey valuable knowledge to the public, to expand the general public's understanding of SoS.

## Data availability

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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## References

Broader scope is key to the future of 'science of science'. (2022). Nature Human Behaviour, *6*(7), 899–900. https://doi.org/10.1038/s41562-022-01424-5

Akella AP, Alhoori H, Kondamudi PR, Freeman C, Zhou H (2021) Early indicators of scientific impact: Predicting citations with altmetrics. Journal Informetrics 15(2):101128. https://doi.org/10.1016/j.joi.2020.101128

Aljuaid H, Iftikhar R, Ahmad S, Asif M Tanvir Afzal M (2021) Important citation identification using sentiment analysis of in-text citations. Telematics and Informatics, *56*. https://doi.org/10.1016/j.tele.2020.101492

Athey S, Tibshirani J, Wager S (2019) Generalized random forests. Annals Statistics 47(2):1179–1203. https://doi.org/10.1214/18-AOS1709

Beltagy I, Lo K Cohan A (2019) SciBERT: A Pretrained Language Model for Scientific Text

Bernal J D (1939) The Social Function of Science: The social function of science

Blei DM, Ng AY, Jordan MI (2003) Latent dirichlet allocation. J. Mach. Learn. Res. 3(null):993–1022

Board N S (1981) Science Indicators, 1980: Report of the National Science Board, *1981*: US Government Printing Office

Bradford SC (1934) Sources of information on specific subjects. Engineering 137:85–86

Bu Y, Ding Y, Liang X, Murray DS (2018) Understanding persistent scientific collaboration. Journal Association Information Science Technology 69(3):438–448. https://doi.org/10.1002/asi.23966

Bu Y, Murray DS, Ding Y, Huang Y, Zhao Y (2018) Measuring the stability of scientific collaboration. Scientometrics 114(2):463–479. https://doi.org/10.1007/s11192-017-2599-0

Budi I, Yaniasih Y (2023) Understanding the meanings of citations using sentiment, role, and citation function classifications. Scientometrics 128(1):735–759. https://doi.org/10.1007/s11192-022-04567-4

Callon M, Courtial JP, Laville F (1991) Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemsitry. Scientometrics 22:155–205

Cattell JM (1906) A Statistical Study of American Men of Science: The Selection of a Group of One Thousand Scientific Men. Science 24(621):658–665. https://doi.org/10.1126/science.24.621.658

Çelik M, Dadaşer-Çelik F, Dokuz A Ş (2011, 15-18 June 2011). Anomaly detection in temperature data using *DBSCAN* algorithm. Paper presented at the 2011 International Symposium on Innovations in Intelligent Systems and Applications

Charlin L Zemel R S (2013) The Toronto Paper Matching System: An automated paper-reviewer assignment system

Checco A, Bracciale L, Loreti P, Pinfield S, Bianchi G (2021) AI-assisted peer review. Humanities Social Sciences Communications 8(1):25. https://doi.org/10.1057/s41599-020-00703-8

Chen CM (2006) CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. Journal American Society Information Science Technology 57(3):359–377. https://doi.org/10.1002/asi.20317

Cohan A, Feldman S, Beltagy I, Downey D, Weld D S (2020) SPECTER: Document-level Representation Learning using Citation-informed Transformers

Devlin J, Chang M-W, Lee K, Toutanova K (2018) *BERT*: Pre-training of Deep Bidirectional Transformers for Language Understanding

Van Eck N, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84(2):523–538

Van Eck NJ, Waltman L (2014) CitNetExplorer: A new software tool for analyzing and visualizing citation networks. Journal Informetrics 8(4):802–823

Edwards KA, Acheson-Field H, Rennane S, Zaber MA (2023) Mapping scientists' career trajectories in the survey of doctorate recipients using three statistical methods. Scientific Reports 13(1):8119. https://doi.org/10.1038/s41598-023-34809-1

Egghe, L & Rousseau R (1990) Introduction to informetrics. Quantitative methods in library, documentation and information science: Elsevier Science Publishers

Fernando T, Denman S, Sridharan S, Fookes C (2018) Soft + Hardwired attention: An LSTM framework for human trajectory prediction and abnormal event detection. Neural Networks 108:466–478. https://doi.org/10.1016/j.neunet.2018.09.002

Fortunato S, Bergstrom C T, Börner K, Evans J A, Helbing D, Milojević S, … Barabási A L (2018) Science of science. Science, 359 (6379). https://doi.org/10.1126/science.aao0185

Galton F (1874) English Men of Science; their Nature and Nurture, 1st ed.). Routledge, London

Galton F (1886) Regression Towards Mediocrity in Hereditary Stature. Journal Anthropological Institute Great Britain Ireland 15:246–263. https://doi.org/10.2307/2841583

Galton F (1891) *Hereditary genius:* D. Appleton

Gao Q, Wen T, Deng Y (2022) A novel network-based and divergence-based time series forecasting method. Inf. Sci. 612(C):553–562. https://doi.org/10.1016/j.ins.2022.08.120

Garfield E (1955) Citation indexes for science: A new dimension in documentation through association of ideas. Science 122(3159):108–111

Garfield E (1965) Can citation indexing be automated. Paper presented at the Statistical association methods for mechanized documentation, symposium proceedings

Garfield E (2006) The History and Meaning of the Journal Impact Factor. jama 295(1):90–93. https://doi.org/10.1001/jama.295.1.90

Garfield E Malin M V (1968) Can Nobel Prize winners be predicted. Paper presented at the 135th meetings of the American Association for the Advancement of Science, Dallas, TX

Gates AJ, Ke Q, Varol O, Barabási AL (2019) Nature's reach: narrow work has broad impact. Nature 575(7781):32–34. https://doi.org/10.1038/d41586-019-03308-7

Ghawi R, Müller S, Pfeffer J (2021) Improving team performance prediction in MMOGs with temporal communication networks. Social Network Analysis Mining 11(1):65. https://doi.org/10.1007/s13278-021-00775-7

Giannakas F, Troussas C, Krouska A, Sgouropoulou C, Voyiatzis I (2022) Multi-technique comparative analysis of machine learning algorithms for improving the prediction of teams' performance. Education Information Technologies 27(6):8461–8487. https://doi.org/10.1007/s10639-022-10900-4

Glänzel W Schubert A (2004) Analysing scientific networks through co-authorship. In Handbook of quantitative science and technology research: The use of publication and patent statistics in studies of S&T systems (pp. 257-276): Springer

Granovsky YV (2001) Is It Possible to Measure Science? V. V. Nalimov's Research in Scientometrics. Scientometrics 52(2):127–150. https://doi.org/10.1023/A:1017991017982

Hill J, Linero A, Murray J (2020) Bayesian Additive Regression Trees: A Review and Look Forward. Annual Review Statistics Its Application 7(1):251–278. https://doi.org/10.1146/annurev-statistics-031219-041110

Hirsch JE (2005) An index to quantify an individual's scientific research output. Proceedings National Academy Sciences USA 102(46):16569–16572. https://doi.org/10.1073/pnas.0507655102

Huang J, Gates AJ, Sinatra R, Barabási AL (2020) Historical comparison of gender inequality in scientific careers across countries and disciplines. Proceedings National Academy Sciences USA 117(9):4609–4616. https://doi.org/10.1073/pnas.1914221117

Ienna G, Rispoli G. The 1931 London Congress: The Rise of British Marxism and the Interdependencies of Society, Nature and Technology. HoST - Journal of History of Science and Technology, 2021, Ludus Association, 15(1):107–130. https://doi.org/10.2478/host-2021-0005

Iqbal S, Hassan S-U, Aljohani NR, Alelyani S, Nawaz R, Bornmann L (2021) A decade of in-text citation analysis based on natural language processing and machine learning techniques: an overview of empirical studies. Scientometrics 126(8):6551–6599. https://doi.org/10.1007/s11192-021-04055-1
Jia T, Wang D, Szymanski BK (2017) Quantifying patterns of research-interest evolution. Nature Human Behaviour 1(4):0078. https://doi.org/10.1038/s41562-017-0078
Jiang H, Fan S, Zhang N, Zhu B (2023) Deep learning for predicting patent application outcome: The fusion of text and network embeddings. Journal Informetrics 17(2):101402. https://doi.org/10.1016/j.joi.2023.101402
Kalmukov Y (2020) An algorithm for automatic assignment of reviewers to papers. Scientometrics 124(3):1811–1850. https://doi.org/10.1007/s11192-020-03519-0
Kankanhalli A (2024) Peer Review in the Age of Generative AI. Journal Association Information Systems 25(1):76–84. https://doi.org/10.17705/1jais.00865
Kim H, Jang H (2024) Predicting research projects' output using machine learning for tailored projects management. Asian Journal Technology Innovation 32(2):346–363. https://doi.org/10.1080/19761597.2023.2243611
Kingsley Zipf G (1932) Selected studies of the principle of relative frequency in language: Harvard university press
Kong L, Zhang W, Hu H, Liang Z, Han Y, Wang D, Song M (2024) Transdisciplinary fine-grained citation content analysis: A multi-task learning perspective for citation aspect and sentiment classification. Journal of Informetrics *18*(3). https://doi.org/10.1016/j.joi.2024.101542
Kormilitzin A, Vaci N, Liu Q, Nevado-Holgado A (2021) Med7: A transferable clinical natural language processing model for electronic health records. Artificial Intelligence Medicine 118:102086. https://doi.org/10.1016/j.artmed.2021.102086
Kuhn T S (1962) The Structure of Scientific Revolutions. Chicago: The structure of scientific revolutions
Lee Rodgers J, Nicewander WA (1988) Thirteen Ways to Look at the Correlation Coefficient. American Statistician 42(1):59–66. https://doi.org/10.1080/00031305.1988.10475524
Li W, Haunert J-H, Knechtel J, Zhu J, Zhu Q, Dehbi Y (2023) Social media insights on public perception and sentiment during and after disasters: The European floods in 2021 as a case study. Transactions GIS 27(6):1766–1793. https://doi.org/10.1111/tgis.13097
Lin Y, Frey CB, Wu L (2023) Remote collaboration fuses fewer breakthrough ideas. Nature 623(7989):987–991. https://doi.org/10.1038/s41586-023-06767-1
Lin Z, Yin Y, Liu L Wang D (2023) SciSciNet: A large-scale open data lake for the science of science research. Scientific Data *10*(1). https://doi.org/10.1038/s41597-023-02198-9
Liu L, Dehmamy N, Chown J, Giles C L Wang D (2021) Understanding the onset of hot streaks across artistic, cultural, and scientific careers. Nature Communications *12*(1). https://doi.org/10.1038/s41467-021-25477-8
Liu L, Wang Y, Sinatra R, Giles CL, Song C, Wang D (2018) Hot streaks in artistic, cultural, and scientific careers. Nature 559(7714):396–399. https://doi.org/10.1038/s41586-018-0315-8
Liu X, Gao K, Liu B, Pan C, Liang K, Yan L, Yu Y (2021) Advances in Deep Learning-Based Medical Image Analysis. Health Data Science 2021:8786793. https://doi.org/10.34133/2021/8786793
Liu Y, Rousseau R (2010) Knowledge diffusion through publications and citations: A case study using ESI-fields as unit of diffusion. Journal American Society Information Science Technology 61(2):340–351. https://doi.org/10.1002/asi.21248
Lotka AJ (1926) The frequency distribution of scientific productivity. Journal Washington academy sciences 16(12):317–323
Merton R K (1973) The sociology of science: Theoretical and empirical investigations: University of Chicago press
Messeri L, Crockett MJ (2024) Artificial intelligence and illusions of understanding in scientific research. Nature 627(8002):49–58. https://doi.org/10.1038/s41586-024-07146-0
Mikolov T, Chen K, Corrado G S Dean J (2013) Efficient Estimation of Word Representations in Vector Space. *Proceedings of Workshop at ICLR, 2013*
Musso MF, Hernández CFR, Cascallar EC (2020) Predicting key educational outcomes in academic trajectories: a machine-learning approach. Higher Education 80(5):875–894. https://doi.org/10.1007/s10734-020-00520-7
Nalimov V & Mul'chenko Z (1969) Naukometriya, the study of the development of science as an information process in Russian. In: Nauka, Moscow
Neumann M, King D, Beltagy I, Ammar W (2019) ScispaCy: Fast and robust models for biomedical natural language processing. Paper presented at the BioNLP 2019 - SIGBioMed Workshop on Biomedical Natural Language Processing, Proceedings of the 18th BioNLP Workshop and Shared Task
Nigel Gilbert G (1977) Referencing as persuasion. Social studies science 7(1):113–122
Nuijten MB, Polanin JR (2020) "statcheck": Automatically detect statistical reporting inconsistencies to increase reproducibility of meta-analyses. Research Synthesis Methods 11(5):574–579. https://doi.org/10.1002/jrsm.1408
Parolo PDB, Pan RK, Ghosh R, Huberman BA, Kaski K, Fortunato S (2015) Attention decay in science. Journal Informetrics 9(4):734–745. https://doi.org/10.1016/j.joi.2015.07.006
Peng B, Wei Y, Qin Y, Dai J, Li Y, Liu A, Wen P (2023) Machine learning-enabled constrained multi-objective design of architected materials. Nature Communications 14(1):6630. https://doi.org/10.1038/s41467-023-42415-y
Persson O, Danell R, Schneider JW (2009) How to use Bibexcel for various types of bibliometric analysis. Celebrating scholarly communication studies: A Festschrift Olle Persson his 60th Birthday 5:9–24
Plehiers P P, Coley C W, Gao H, Vermeire F H, Dobbelaere M R, Stevens C V, … Green W H (2020) Artificial Intelligence for Computer-Aided Synthesis In Flow: Analysis and Selection of Reaction Components. Paper presented at the Frontiers in Chemical Engineering
Porter A, Chubin D (1985) An indicator of cross-disciplinary research. Scientometrics 8(3-4):161–176
Prado EB, Moral RA, Parnell AC (2021) Bayesian additive regression trees with model trees. Statistics Computing 31(3):20. https://doi.org/10.1007/s11222-021-09997-3
Price DDS (1976) A general theory of bibliometric and other cumulative advantage processes. Journal American Society Information Science 27:292–306
Price D J D S (1963) Little science, big science: Columbia University Press
Price S, Flach PA (2017) Computational support for academic peer review: a perspective from artificial intelligence. Commun. ACM 60(3):70–79. https://doi.org/10.1145/2979672
Van Raan AFJ (2004) Sleeping Beauties in science. Scientometrics 59(3):467–472. https://doi.org/10.1023/B:SCIE.0000018543.82441.f1
Reimers N, Gurevych I (2019) Sentence-BERT: Sentence Embeddings using Siamese BERT-Networks. Paper presented at the Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)
Sankar CP, Thumba DA, Ramamohan TR, Chandra SSV, Satheesh Kumar K (2020) Agent-based multi-edge network simulation model for knowledge diffusion through board interlocks. Expert Systems Applications 141:112962. https://doi.org/10.1016/j.eswa.2019.112962
Saranya A, Subhashini R (2023) A systematic review of Explainable Artificial Intelligence models and applications: Recent developments and future trends. Decision Analytics Journal 7:100230. https://doi.org/10.1016/j.dajour.2023.100230
Schubert E Gertz M (2017, 2017//). Intrinsic t-Stochastic Neighbor Embedding for Visualization and Outlier Detection. Paper presented at the Similarity Search and Applications, Cham
Schuler MS, Rose S (2017) Targeted Maximum Likelihood Estimation for Causal Inference in Observational Studies. American Journal Epidemiology 185(1):65–73. https://doi.org/10.1093/aje/kww165
Shanahan D (2016) A peerless review? Automating methodological and statistical review. Retrieved from https://blogs.biomedcentral.com/bmcblog/2016/05/23/peerless-review-automating-methodological-statistical-review/
Shneider AM (2009) Four stages of a scientific discipline; four types of scientist. Trends Biochemical Sciences 34(5):217–223. https://doi.org/10.1016/j.tibs.2009.02.002
Singh A, D'Arcy M, Cohan A, Downey D & Feldman S (2022) SciRepEval: A Multi-Format Benchmark for Scientific Document Representations. Paper presented at the Conference on Empirical Methods in Natural Language Processing
Small H (1973) Co-citation in the scientific literature: A new measure of the relationship between two documents. Journal American Society Information Science 24(4):265–269. https://doi.org/10.1002/asi.4630240406
Small HG (1978) Cited documents as concept symbols. Social Studies Science 8(3):327–340
De Solla Price, D J (1975) *Science since Babylon* (300017987): Yale University Press New Haven
Sugimoto CR (2021) Scientific success by numbers. Nature 593(7857):30–31. https://doi.org/10.1038/d41586-021-01169-7
Thelwall M Kousha K (2023) Technology assisted research assessment: algorithmic bias and transparency issues. Aslib Journal of Information Management. https://doi.org/10.1108/AJIM-04-2023-0119
Tohalino JAV, Amancio DR (2022) On predicting research grants productivity via machine learning. Journal Informetrics 16(2):101260. https://doi.org/10.1016/j.joi.2022.101260
Vilone G Longo L (2020) Explainable Artificial Intelligence: a Systematic Review. *arXiv*:2006.00093. https://doi.org/10.48550/arXiv.2006.00093
Wager S, Athey S (2018) Estimation and inference of heterogeneous treatment effects using random forests. Journal American Statistical Association 113(523):1228–1242. https://doi.org/10.1080/01621459.2017.1319839

Wang Y, Jones B F Wang D (2019) Early-career setback and future career impact. Nature Communications, *10*(1). https://doi.org/10.1038/s41467-019-12189-3
Wu L, Wang D, Evans JA (2019) Large teams develop and small teams disrupt science and technology. Nature 566(7744):378–382. https://doi.org/10.1038/s41586-019-0941-9
Xiao P (2011) A Review of the Scientific Information Conference in1958and Its Historical Significance. Information Documentation Services 32(05):27–31. https://kns.cnki.net/kcms2/article/abstract?v=tJ8vF22QX-oThckOgSpWscVgn4pI6CnfHyStwZgkqDBM9eTTx3dRS-2uoSBXiEUdi8FmAtMG1RQUiwLPBWyWNzBYdYuG6-8jtA6v8v9Lj462jyvWhDdPPXbmMGI8OjUH2_wvB4YFo-k=&uniplatform=NZKPT&language=CHS
Xu F, Wu L, Evans J (2022) Flat teams drive scientific innovation. *Proceedings of the National Academy of Sciences of the United States of America*, *119*(23). https://doi.org/10.1073/pnas.2200927119
Xue J, Chen J, Chen C, Zheng C, Li S, Zhu T (2020) Public discourse and sentiment during the COVID 19 pandemic: Using Latent Dirichlet Allocation for topic modeling on Twitter. PLoS ONE 15(9):e0239441. https://doi.org/10.1371/journal.pone.0239441
Yang Y, Chawla NV, Uzzi B (2019) A network's gender composition and communication pattern predict women's leadership success. Proceedings National Academy Sciences USA 116(6):2033–2038. https://doi.org/10.1073/pnas.1721438116
Yin Y, Gao J, Jones BF, Wang D (2021) Coevolution of policy and science during the pandemic. Science 371(6525):128–130. https://doi.org/10.1126/science.abe3084
Yoo HS, Jung YL, Jun S-P (2023) Prediction of SMEs' R&D performances by machine learning for project selection. Scientific Reports 13(1):7598. https://doi.org/10.1038/s41598-023-34684-w
Yu H, Yang LT, Zhang Q, Armstrong D, Deen MJ (2021) Convolutional neural networks for medical image analysis: State-of-the-art, comparisons, improvement and perspectives. Neurocomputing 444:92–110. https://doi.org/10.1016/j.neucom.2020.04.157
Zeng A, Shen Z S, Zhou J L, Fan Y, Di Z R, Wang Y G, … Havlin S (2019). Increasing trend of scientists to switch between topics. Nature Communications, 10. https://doi.org/10.1038/s41467-019-11401-8
Zeng T, Acuna DE (2020) Modeling citation worthiness by using attention-based bidirectional long short-term memory networks and interpretable models. Scientometrics 124(1):399–428. https://doi.org/10.1007/s11192-020-03421-9
Zhang X, Wang L, Helwig J, Luo Y, Fu C, Xie Y, … Ji S (2023). Artificial Intelligence for Science in Quantum, Atomistic, and Continuum Systems
Zhang X-h, Qian K, Ren J-j, Jia Z-p, Jiang T-p, Zhang Q (2019) Measurement and analysis of content diffusion characteristics in opportunity environmentswith Spark. Frontiers Information Technology Electronic Engineering 20(10):1404–1414. https://doi.org/10.1631/FITEE.1900137
Zhao Z, Bu Y, Kang L, Min C, Bian Y, Tang L, Li J (2020) An investigation of the relationship between scientists' mobility to/from China and their research performance. Journal Informetrics 14(2):101037. https://doi.org/10.1016/j.joi.2020.101037

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## Author contributions
JH: design of the work, and supervised the development of the research; BZ: literature collection, wrote and revised the manuscript; HL: wrote and revised the manuscript; WL: wrote the manuscript. All authors contributed to manuscript revision and approved the final manuscript.

## Competing interests
The authors declare no competing interests.

## Ethical approval
Ethical approval was not required as the study did not involve human participants.

## Informed consent
Informed consent was not required as the study did not involve human participants.

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# Research contribution of bibliometric studies related to sustainable development goals and sustainability

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**Abstract**
This bibliometric study analyzes 1433 former reviews on Sustainable Development Goals (SDGs) and Sustainability, providing a comprehensive overview of the evolving research landscape in this domain. Notably, we observe a substantial annual growth rate of 74% in publications and a remarkable 171% increase in total citations from 2016 to 2022, reflecting a growing interest in this area. We identify the leading countries and institutions contributing to quantitative reviews on SDGs and Sustainability. SDG 12 (Sustainable Consumption and Production) emerges as the most extensively studied and is highly represented in influential journals like *Sustainability* and the *Journal of Cleaner Production*. Across various research fields, SDGs 12 and 11 (Sustainable Cities and Communities) stand out, with SDGs 4 (Quality Education), 5 (Gender Equality), and 15 (Life on Land) showing significance in specific domains. Thematic analysis reveals key topics like environmental protection, circular economy, life cycle assessment, and supply chain management, with strong connections to SDG 12. Further clusters highlight environmental management, renewable energy, and energy policy linked to SDG 7 (Affordable and Clean Energy), along with a smaller cluster focusing on urbanization driven by SDG 11. Network analysis emphasizes the critical roles of SDGs 12 and 9 (Industry Innovation and Infrastructure) in achieving a sustainable future. However, alternative social network indicators highlight the potential influence of SDGs 8 (Decent Work and Economic Growth), 16 (Peace, Justice and Strong Institutions), and 17 (Partnerships for the Goals) on other goals. Intriguingly, mainstream SDG research predominantly focuses on SDGs 3 and 7, presenting challenges due to the volume and complexity of related publications. While SDG 7 could find suitable outlets in leading journals, addressing SDG 3's (Good Health and Well Being) complexity remains a formidable task. Nevertheless, conducting bibliometric studies on SDGs 3, 7, and 13 (Climate Action) offers promising opportunities in future if the associated challenges are addressed effectively.

**Keywords** Sustainable Development Goal · Sustainability · Bibliometrics · Bibliometric of bibliometrics · Social network analysis · Energy policy · Gender equality · Science mapping

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## 1 Introduction

The Sustainable Development Goals (SDGs), or the Global Goals, are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity [1]. Adopted by the United Nations in 2015, the 17 SDGs aim to transform our world by 2030 through a comprehensive approach to sustainable development [2]. These goals address various social, economic, and environmental challenges, including poverty, inequality, climate change, and conflict [3]. The SDGs are crucial for countries, organizations, and individuals to align their efforts toward a common and ambitious vision for a better future [2, 4]. Given the significance of the SDGs and their potential to bring about positive change in our world, in this paper, we review the former reviews on SDGs to contribute to the ongoing conversation.

The SDGs have been the focus of extensive research and analysis since their adoption in 2015 [5, 6]. The current state of the art of research on SDGs reflects a multidisciplinary and interdisciplinary approach, with scholars and practitioners from various fields, such as economics, sociology, environmental science, and political science, among others, contributing to the understanding of the goals and their implementation [7–9].

A significant body of research has focused on the progress made toward achieving the SDGs, including assessments of the current state of play and trends in the implementation of the goals at the global, regional, and national levels [10–12]. Unfortunately, none curate a holistic picture of the state of research. Additionally, a growing body of research has explored the challenges and barriers to the implementation of the SDGs, including the lack of resources and funding, the lack of effective governance and institutions, and the challenges posed by conflicting interests and power dynamics [13–15]. These studies have highlighted the importance of innovative and inclusive approaches to implementing the SDGs and the need for strong partnerships between governments, the private sector, and civil society.

A review of the former literature reveals many SDG research areas, reflecting the goals' wide-ranging and complex nature. Some of the key research areas in the field of SDGs include:

Progress and implementation: Research in this area focuses on tracking and assessing the progress made through achieving the SDGs, including the identification of gaps and challenges in the implementation of the goals [16].

Economic and financial dimensions: Research in this area explores the economic and financial dimensions of the SDGs, including the identification of financing sources, the development of economic and financial policies, and the analysis of the economic and financial implications of the goals [17].

Environmental sustainability: Research in this area focuses on the environmental aspects of the SDGs, including the protection and restoration of ecosystems, the reduction of greenhouse gas emissions, and the development of sustainable and resilient communities [18].

Social inequality and poverty reduction: Research in this area focuses on the social dimensions of the SDGs, including the reduction of poverty, the promotion of gender equality, and the protection of human rights [19].

Political and institutional dimensions: Research in this area focuses on the political and institutional dimensions of the SDGs, including the role of governments, the private sector, and civil society in the implementation of the goals, as well as the development of governance structures and institutions to support sustainable development [20].

Data and measurement: Research in this area focuses on the development of data and measurement systems to track and assess progress towards the SDGs, including the development of indicators, methodologies, and data collection and analysis tools [21, 22].

Interdisciplinary and transdisciplinary approaches: Research in this area focuses on interdisciplinary and transdisciplinary approaches to sustainable development, including the integration of different perspectives and disciplines in the analysis and implementation of the SDGs [23].

Reviews: Precisely, research in this area attempts to classify and summarize former works depicting the progress made on specific SDGs. For example, SDG 3 [24], SDG 6 [25], SDGs 8 and 12 [26], etc. These comprehensive articles serve as critical bridges between the existing body of knowledge on SDGs and the current state of research, making them invaluable resources for scholars, students, and practitioners alike.

These are just a few examples of the many SDG research fronts. The field constantly evolves, and new research areas are emerging as the goals continue gaining attention and importance in the global development agenda. The current state of the art of SDG research reflects a growing recognition of the importance of the goals for sustainable development and the need for more action to achieve them. It also underscores the need for continued research and analysis to understand the challenges and opportunities associated with implementing the SDGs and the role different actors can play in promoting sustainable development [11, 27].

Given the dynamic, diverse, multidisciplinary, and interdisciplinary nature of research on SDGs, frequent, systematic, and timely assessment of the evolving body of knowledge is imperative to guide future research directions [28]. It has become increasingly challenging to gain meaningful insights from the vast literature using traditional means. Fortunately, several retrospectives have emerged to bridge the gap. For example, applying bibliometrics, Sweileh [24] attempts to review the literature focusing on SDG 3, i.e., good health and well-being. González García et al. [29] analyses the literature on SDG 4 i.e., quality education. Raman et al. [11] present a comprehensive analysis of SDGs 7 and 13, i.e., affordable and clean energy and climate action, respectively; Sharifi et al. [30] summarize the literature on SDGs 13 and 16, i.e., climate change and peace. In one of the recent works, Raman et al. [27] attempt to summarize the research advocating the fulfilment of SDGs 5, 8, and 10, i.e., gender equality, decent work and economic growth, and reduced inequalities. Notably, quantitative reviews of SDGs have proliferated significantly, prompting a need to review these prior retrospectives. This growing body of research underscores the importance of ongoing bibliometric and scientometric analysis in furthering our understanding of the multifaceted SDGs and providing insights for both researchers and policymakers.

Furthermore, the likelihood of certain SDGs being overrepresented in bibliometric assessment literature suggests that some SDGs remain insufficiently explored or unexplored in this context. Another intriguing aspect that could benefit bibliometricians, enthusiasts, and researchers in various SDGs is understanding the utilization patterns of different bibliometric methods and frameworks. This insight would reveal which methods, tools, and frameworks are frequently employed and which ones are underutilized. Analyzing the less commonly used methods opens a realm of untapped analysis opportunities. Additionally, identifying key bibliometric assessment efforts related to SDGs can shed light on emerging research themes within these goals and offer valuable insights to researchers and policymakers alike. Such information can assist policymakers in prioritizing emerging "thrust areas" that warrant research attention. In essence, we propose to offer a meta-analysis to empower researchers and institutions to make informed decisions. Precisely, we ask the following research questions (RQs):

- RQ1. What is the trend of bibliometric research in SDGs?
- RQ2. How do different bibliometric studies relate to various SDGs?
- RQ3. What are the top fields of research (FoR), and what topics are emergent in the research domain?

By addressing the RQs, we make several important contributions. We firmly believe our novel approach benefits both the de novo and seasoned scholars alike. Our extensive range of performance and network analyses is formidable to those fresh to the field of knowledge. They may specifically appreciate our exposition of the research trend, identification of the seminal works and notable scholars to follow, their affiliations denoting the research hotspots, and the range of thematic diversity evident in the research domain. At the same time, the seasoned academic may appreciate our introspection of the SDG maps and future research directions. Conversely, the policy makers gain insights for identifying areas where future sponsorship should concentrate.

The remaining part of the paper is structured as follows: Sect. 2 briefs the research methods, and Sect. 3 discusses the results. Section 4 deliberates on the emerging research topics, followed by our discussions and conclusions in Sect. 5.

## 2 Methodology

As we intend to analyze the bibliometric studies related to SDGs using bibliometric methods, a brief introduction to the field of bibliometrics and associated fields such as Scientometrics and Informetrics is attempted. Bibliometrics can be traced back at least to the late nineteenth century when explorations to study subject scattering in publications, the growth of literature and history of science, etc., using statistical methods began. The frequency distribution of scientific publications of Physicists and Chemists by Lotka [31] is treated as one of the first attempts to determine scientific productivity. While the key proposition of Lotka later gained popularity as Lotka's law of productivity, the seminal work by Bradford [32] was dubbed Bradford's law of scattering. Bernal [33] put forward the social function of Science and laid the foundation of Science of Science, and Zipf [34] came out with inverse relation law in many physical and social systems known as Zipf's law. The formalism of quantitative measures for measuring science was introduced by Price [35], whom Garfield and others acknowledged as the father of modern Scientometrics. Garfield introduced SCI or Science Citation Index, an indexing system for scientific literature, which can be regarded as a milestone development or bridge in the transition of pre-modern Scientometrics or science of science to 'Scientometrics'. While this transition happened, several important works were done on the underlying mechanism of scientific progress. Price [35] brought out the exponential curve of science. Merton [36] extended the work of Bernal in a sociologistic perspective and strengthened science's 'social organization'. The introduction of bibliographic coupling [37], the introduction of historiographies by Garfield et al. [38], and the introduction of networks of scientific publications by Price [35] marked the take-off of modern Scientometrics. It allowed the possibility of systematic analysis of scientific literature via network science and other quantitative methods.

Small [39] and Marshakova [40] independently introduced the co-citation of documents as a method for measuring the relationship between documents. Perhaps all these achievements triggered the official coining of terms like 'bibliometrics' by Pritchard [41], 'Scientometrics' by Nalimov and Mulchenko [42], and 'informetrics' by Nacke [43]. These triumvirate fields evolved by introducing many indicators, methods for assessment and mapping of science, and several software packages such as VOSViewer [44] that incorporated these methods. An important development in the indicator domain was through Hirsch [45] in the form of the *h*-index, which was initially appreciated and soon criticized for its limitations in individual productivity assessment. Several indices, like the *g*-index [46], *t* and *f* indices [47], etc., were developed, and these are widely dubbed as *h*-type indicators, and one of the recent in this category is the Ψ-index [48]. Though these indices have some limitations, they are inspired by the h-index and some of its variants and are used for the development of diligently designed frameworks for institutional performance assessment [49] and for collaboration recommendation systems [50].

In this review, the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol developed by Paul et al. [51] and used extensively by other authors [27, 52] is adopted to guide the assembling, arranging, and assessing tasks (see Fig. 1). We disclose and explain the methodological choices at each stage of the protocol as follows:

### 2.1 Assembling

The initial step, known as assembling, involves gathering publications for examination. As this work deals with a bibliometric analysis of bibliometric studies related to SDG research, our data comprises works in the intersection of SDG, sustainability, and bibliometric research. The following search query is used to retrieve the bibliographic data from Scopus on February 28, 2023. Scopus is widely acknowledged and frequently utilized for quantitative analyses and it is the premier multi-disciplinary database containing peer-reviewed literature [53]. We selected the study period between 2016 and 2022 to focus on recent developments following the formal adoption of the UN SDG in September 2015. We applied the following search to retrieve a total of 1711 publications.

*TITLE-ABS ((“SDG” OR “sustainable development” OR (sustainability)) AND (bibliometric OR scientometric OR “Science mapping” OR “citation analysis” OR bibliographic)) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “re”) OR LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE, “ch”) OR LIMIT-TO (DOCTYPE, “cr”)) AND (LIMIT-TO (PUBYEAR,2022) OR LIMIT-TO (PUBYEAR,2021) OR LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016) OR LIMIT-TO (PUBYEAR, English)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SRCTYPE, “j”)).*

### 2.2 Arranging

In the SPAR-4-SLR protocol, the arranging stage involves organizing codes and purifying articles by applying exclusion and inclusion criteria to the results obtained from the search. For organization, we downloaded the bibliometric data of articles from Scopus and sorted them by the article title, journal title, author name, institute affiliation, country of affiliation, author keyword, number of citations, and SDG linkage with articles. We utilized SciVal to identify the SDG linkage with articles. As for purification, we excluded 278 articles as they could not be associated with SDGs.

### 2.3 Assessing

In the last stage, assessment, evaluation, and reporting play a crucial role. The article's evaluation section highlights the analysis approach and research constraints. In this research, we utilized various software tools such as Scival [54], VOSviewer [44], Rawgraphs [55], SDG Toolkit [56], and MS Excel, depending on the specific requirements. MS Excel was employed for data filtering, sorting, listing, and graph creation. Scival played a key role in identifying the most and least researched SDGs, mapping SDGs to journals, countries, institutions, and authors, as well as identifying emerging research topics and their SDG focus. VOSViewer was primarily used for visualizing keyword co-occurrence mapping and co-citation mapping of SDGs. Rawgraphs aided in designing the Sankey diagram for mapping the top countries, institutions, and journals. SDG Mapper was used to determine the percentage of SDG mappings of keywords in different clusters, while

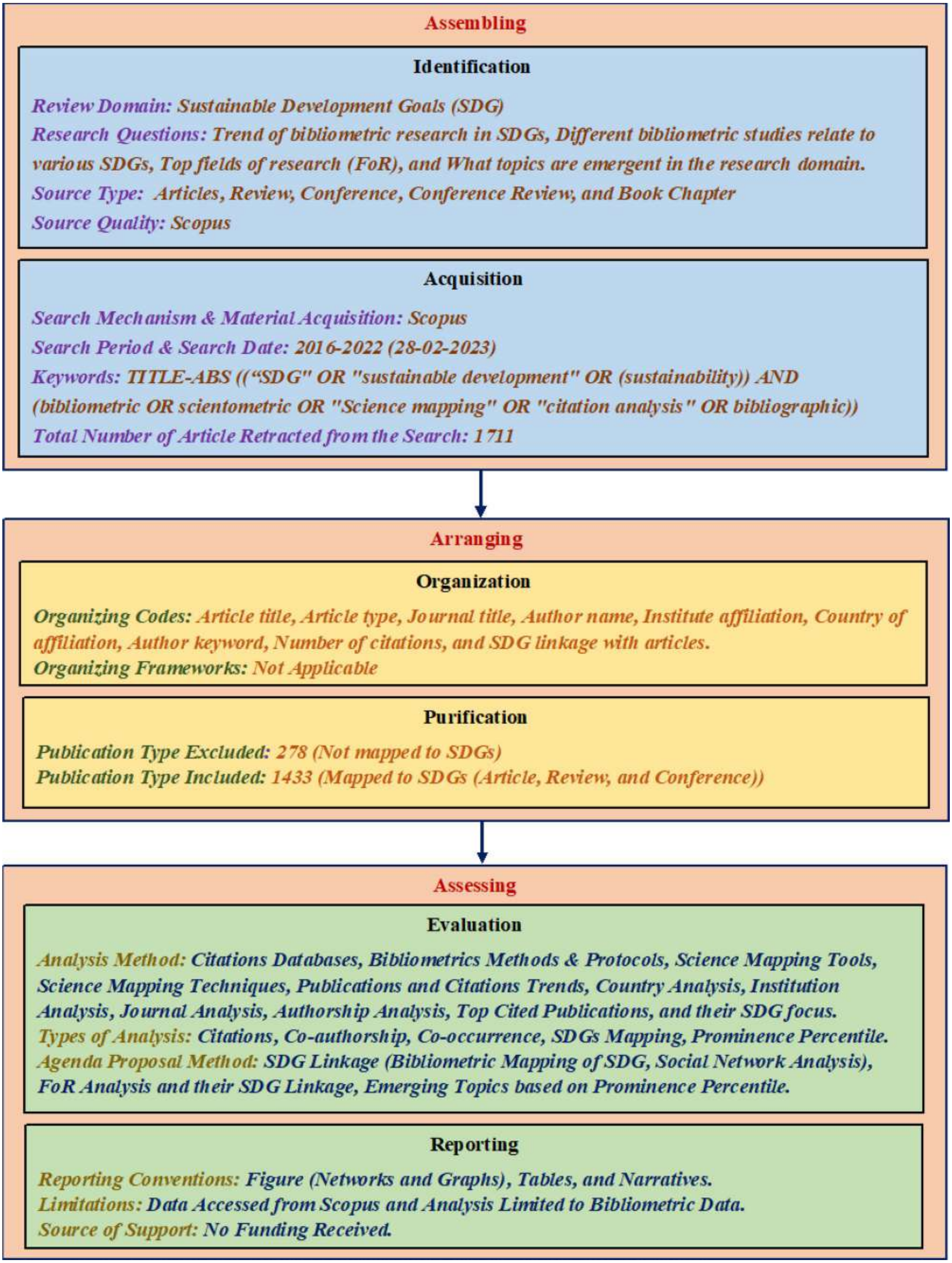



**Fig. 1** The SPAR-4-SLR protocol

SDGToolkit was employed to construct an SDG network based on eigenvector and betweenness for analyzing the network of SDG goals.

## 3 Results and discussions

In accordance with the SPAR-4-SLR protocol, our analysis encompasses 1433 bibliometric studies on SDGs and sustainability. Initially, we categorize the study articles by their publication type, the search engines employed for collecting bibliographic data, the study methods they employ, and the science mapping tools and techniques they utilize. Subsequently, we delve into an examination of the trends in publications and citations, the authors' affiliations, including their countries and institutions, and the sources in which these studies are published. Furthermore, we present an in-depth analysis of the contributing authors. After the descriptive analysis, we proceed to provide a summary of the most highly cited publications and their corresponding SDG maps. Additionally, we compile a summary of keyword co-occurrence patterns, mapping them to their respective relevant SDG(s).

Table 1 summarizes bibliometric studies on various SDGs, revealing varying research focus. SDG12 (Responsible Consumption and Production) garnered the most studies at 699, followed by SDG9 (Industry, Innovation, and Infrastructure) with 535, and SDG8 (Decent Work and Economic Growth) with 586. In contrast, SDG5 (Gender Equality) saw only 26 bibliometric studies potentially suggesting scope for future research.

### 3.1 Citations databases (search engines)

Upon careful observation of the study articles, we find that scholars retrieve data from several search engines, such as Scopus, WoS, Google Scholar, and PubMed, both in isolation and in combination. However, most studies relied on Scopus or Web of Science (WoS). Table 2 presents the top three cited publications on SDGs, categorized by publication type and the search engines in which they appear.

Geissdoerfer et al. [57], a review of SDG12 is the top-cited article (TC: 2556) in WoS, followed by D'Amato et al. [58] and Olawumi & Chan [25], while Cheng [59] is the top-cited SDG article in Scopus (TC: 506) followed by Chen et al.[60] and Zyoud & Fuchs-Hanusch [61] cited 270 and 244 times, respectively. D'Amato et al. [58] cover multiple SDGs, such as SDG4, SDG8, and SDG12, while Olawumi and Chan[25] review articles on SDG6, SDG8, and SDG11. Among the top-cited reviews in Scopus, Cheng [59] reviews articles on SDG12, followed by Chen et al. [60] addressing

**Table 1** Bibliometric studies on SDGs

| TP | SDG |
|---|---|
| 699 | SDG12 (Responsible Consumption and Production) |
| 586 | SDG8 (Decent Work and Economic Growth) |
| 535 | SDG9 (Industry, Innovation and Infrastructure) |
| 251 | SDG4 (Quality Education) |
| 246 | SDG13 (Climate Action) |
| 201 | SDG7 (Affordable and Clean Energy) |
| 200 | SDG11 (Sustainable Cities and Communities) |
| 120 | SDG2 (Zero Hunger) |
| 101 | SDG6 (Clean Water and Sanitation) |
| 100 | SDG15 (Life on Land) |
| 83 | SDG3 (Good Health and Well-being) |
| 68 | SDG10 (Reduced Inequalities) |
| 67 | SDG16 (Peace, Justice and Strong Institutions) |
| 50 | SDG14 (Life Below Water) |
| 49 | SDG1 (No Poverty) |
| 26 | SDG5 (Gender Equality) |
| 3 | SDG17 (Partnerships for the Goals) |

This table presents a summary of the SDG mapping of the study articles. SDG = sustainable development goals, and TP = total publications (includes SDG overlaps) on the search date

**Table 2** Top cited articles based on the citation database and publication type

| TC | Author(s) | Publication Type | SDG Focus | Search Engine |
|---|---|---|---|---|
| 2556 | Geissdoerfer et al. [57] | Review | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | Web of Science (TP: 852) |
| 455 | D'Amato et al. [58] | Article | 4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 348 | Olawumi & Chan [25] | Review | 6 CLEAN WATER AND SANITATION; 8 DECENT WORK AND ECONOMIC GROWTH; 11 SUSTAINABLE CITIES AND COMMUNITIES | |
| 506 | Cheng [59] | Article | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | Scopus (TP: 601) |
| 270 | Chen et al. [60] | Article | 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 16 PEACE, JUSTICE AND STRONG INSTITUTIONS | |
| 244 | Zyoud & Fuchs-Hanusch [61] | Review | 4 QUALITY EDUCATION | |

This table shows the top three cited review articles on SDGs indexed in Web of Science and Scopus. TP = total publications, and TC = total citations on the search date

SDG8, SDG9, and SDG16, and Zyoud & Fuchs-Hanusch's [61] focusing on SDG4. It is interesting to note that SDG12 (Responsible Consumption and Production) is the focus of two highly cited publications from both databases, while SDG8 (Decent Work and Economic Growth) is covered in three of the six listed publications. Additionally, the table demonstrates that influential reviews on SDGs are interdisciplinary, with multiple SDGs being addressed in various survey papers, possibly using various methods and review protocols.

## 3.2 Bibliometrics methods and review protocols

Many papers guide literature reviews, but few offer a definitive and transparent process for researchers to rely on. PRISMA and SPAR-4-SLR protocols aim to improve transparency and reliability in systematic reviews. The adoption of PRISMA has widely enhanced the quality and transparency of reporting in systematic reviews and meta-analyses. SPAR-4-SLR, introduced by Paul et al. [51], is an extension of the original SPAR framework, developed to guide researchers in conducting systematic mapping studies.

Our manual review of the study articles revealed that 156 articles followed the PRISMA protocol, while only 16 applied the SPAR-4-SLR protocol owing to its later inclusion, indicating the overwhelming popularity of PRISMA over SPAR-4-SLR for systematic reviews. As there is no explicit declaration about the usage of protocols in these articles, without in-depth assessment, it is not easy to understand whether such studies were conducted systematically or intended for literature reviews. Also, the usage of multiple protocols (exploring whether one can complement the other or not) for SLR, other quantitative methods, including sophisticated bibliometric methods and combinations of those, qualitative methods, and mixed-methods, etc., are not that evident from the body of literature we analyzed. Table 3 shows the top-cited reviews following the PRISMA and SPAR-4-SLR protocols and maps them to their respective SDG(s) focus.

Interestingly, our findings reveal a pattern among the top three reviews, i.e., while the top three using the PRISMA protocol are linked to SDG 3, SDG 4, SDG 10, SDG 11, and SDG 12, the top three for SPAR-4-SLR are associated with SDG 4, SDG 7, SDG 8, SDG 9, SDG 11, SDG 12, and SDG 13. As we delve into the exploration of science mapping tools in the next section, it's noteworthy that the utilization of both PRISMA and SPAR-4-SLR protocols appears to provide comprehensive coverage across a wide range of SDGs.

**Table 3** Top cited PRISMA and SPAR-4-SLR protocol-based publications

| TC | Author(s) | SDG focus | Protocol |
|---|---|---|---|
| 103 | Hallinger & Chatpinyakoop [62] | 4 QUALITY EDUCATION; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | PRISMA (156) |
| 68 | Strifler et al. [63] | 3 GOOD HEALTH AND WELL-BEING | |
| 58 | Kong et al. [64] | 10 REDUCED INEQUALITIES; 11 SUSTAINABLE CITIES AND COMMUNITIES; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 24 | Kumar et al. [65] | 4 QUALITY EDUCATION; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | SPAR-4-SLR (16) |
| 4 | Raman et al. [27] | 7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION | |
| 3 | Secinaro et al. [66] | 11 SUSTAINABLE CITIES AND COMMUNITIES | |

This table presents the top-cited systematic review papers based on PRISMA and SPAR-4-SLR protocols. TC = total citations on the search date

### 3.3 Science mapping tools

Various science mapping tools, including Bibexcel, Gephi, VOSviewer, SciMAT, CiteSpace, and Bibliometrix, have been employed in bibliometric analyses. Moral-Muñoz et al. [67] compared these tools comprehensively, highlighting their strengths and weaknesses and providing guidance on which tool might be most appropriate for different research questions and objectives. Bibexcel analyzes scientific publications through co-authorship, citation, and co-citation analysis [68]. Gephi visualizes social and citation networks [69]. VOSviewer creates and visualizes bibliometric maps of relationships between papers, authors, and journals [44]. SciMAT analyzes co-citation patterns, text content, and network structures [70]. CiteSpace performs co-citation analysis to identify key concepts, authors, and research trends [71]. Bibliometrix is an R-package for comprehensive science mapping analysis, including bibliometric analysis, network analysis, and visualization [72].

Table 4 provides information on the top-cited articles that have used various science mapping tools in bibliometric studies on SDGs. Interestingly, the most widely used tool is VOSviewer, followed by CiteSpace and Bibliometrix. Our analysis reveals that the most common SDGs studied using these tools are SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 12 (Responsible Consumption and Production). It is also interesting to note that some articles have used multiple tools, such as Rashidi et al. [73], who have used both Bibexcel and Bibliometrix.

In summary, Table 4 highlights the prevalence of science mapping tools in bibliometric studies on SDGs, with VOSviewer emerging as the most widely adopted tool, closely followed by CiteSpace and Bibliometrix. Our analysis highlights that researchers predominantly employ these tools to investigate SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 12 (Responsible Consumption and Production). Additionally, it's worth noting that some studies utilize multiple tools, showcasing the versatility and adaptability required in this dynamic research domain. As we transition to the exploration of science mapping techniques in the next section, these findings underline the significance of science mapping tools in advancing our understanding of SDGs and the importance of selecting the right tools for the right research questions, ultimately contributing to the overarching goals of sustainability.

**Table 4** Top cited SDG articles for science mapping tools

| TC | Authors | SDG focus | Tool |
|---|---|---|---|
| 511 | Cheng [59] | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | Bibexcel (TP: 43) https://homepage.univie.ac.at/juan.gorraiz/bibexcel/ |
| 76 | Mura et al. [74] | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 72 | Rashidi et al. [73] | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 511 | Cheng [59] | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | Gephi (TP: 49) https://gephi.org/ |
| 228 | Feng et al. [75] | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 76 | Dhamija and Bag [76] | 4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 251 | Zyoud and Fuchs-Hanusch [61] | 4 QUALITY EDUCATION | VOSviewer (TP: 536) https://www.vosviewer.com/ |
| 164 | Duque-Acevedo et al. [77] | 4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 126 | Abad-Segura et al. [78] | 4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 75 | Abduljabbar et al. [79] | 11 SUSTAINABLE CITIES AND COMMUNITIES | SciMAT (TP: 49) https://sci2s.ugr.es/scimat/ |
| 72 | Furstenau et al. [80] | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 68 | Agusdinata et al. [81] | 7 AFFORDABLE AND CLEAN ENERGY | |
| 354 | Olawumi and Chan [25] | 6 CLEAN WATER AND SANITATION; 8 DECENT WORK AND ECONOMIC GROWTH; 11 SUSTAINABLE CITIES AND COMMUNITIES | CiteSpace (TP: 218) https://citespace.podia.com/ |
| 181 | Dos et al. [82] | 8 DECENT WORK AND ECONOMIC GROWTH | |
| 168 | Li et al. [83] | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE | |
| 172 | Di et al. [84] | 4 QUALITY EDUCATION; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | Bibliometrix (TP: 171) https://www.bibliometrix.org/ |
| 111 | Schöggl et al. [85] | 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 84 | Sharma et al. [86] | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |

**Table 4** (continued)

This table shows the top-cited SDG article using various science mapping tools. TP = total publication, and TC = total citations on the search date

**Table 5** Top cited SDG articles on various science mapping techniques

| TC | Authors | SDG focus | Science mapping technique |
|---|---|---|---|
| 124 | Pizzi et al. [87] | 4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH; 10 REDUCED INEQUALITIES | Bibliographic coupling (TP: 125) |
| 76 | Bartolacci et al. [88] | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE | |
| 76 | Mura et al. [74] | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 511 | Cheng [59] | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | Co-citation analysis (TP: 347) |
| 158 | Zhang & Li [89] | 11 SUSTAINABLE CITIES AND COMMUNITIES | |
| 126 | Abad-Segura et al. [78] | 4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 353 | Olawumi & Chan [25] | 6 CLEAN WATER AND SANITATION; 8 DECENT WORK AND ECONOMIC GROWTH; 11 SUSTAINABLE CITIES AND COMMUNITIES | Co-word analysis (TP: 185) |
| 149 | Si et al. [90] | 11 SUSTAINABLE CITIES AND COMMUNITIES | |
| 101 | Zhu & Hua [91] | 8 DECENT WORK AND ECONOMIC GROWTH | |
| 164 | Duque-Acevedo et al. [77] | 4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | Co-authorship analysis (TP: 130) |
| 76 | Garrigos-Simon et al. [92] | 8 DECENT WORK AND ECONOMIC GROWTH; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |
| 72 | Rashidi et al. [73] | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | |

This table shows the top-cited SDG article using various science mapping techniques. TP = total publications, and TC = total citations on the search date

### 3.4 Science mapping techniques

On manual review of publications, we discovered that 125, 347, 185, and 130 publications apply bibliographic coupling, co-citation, co-word, and co-authorship analyses, respectively. Table 5 shows the top three cited publications for the four science mapping techniques. Further investigation reveals that SDG 12 on responsible production and consumption is commonly featured across all techniques.

Thus, the consistent focus on SDG 12 across all four science mapping techniques underscores its significance in the literature. This implies a widespread recognition of SDG 12's importance in sustainability. Researchers employ various mapping methods to explore its different aspects, potentially influencing policy and practice. This finding encourages deeper exploration of SDG 12's implications and applications in academia and the real world, highlighting its relevance and providing direction for future research.

Along with the science mapping tools and techniques, understanding the publication and citation trends is vital in recognizing the evolving landscape of research in the field of SDGs and sustainability. As we delve into the specific trends, it's important to gain insights into the trajectories that this research area is taking and the SDGs that are at the forefront

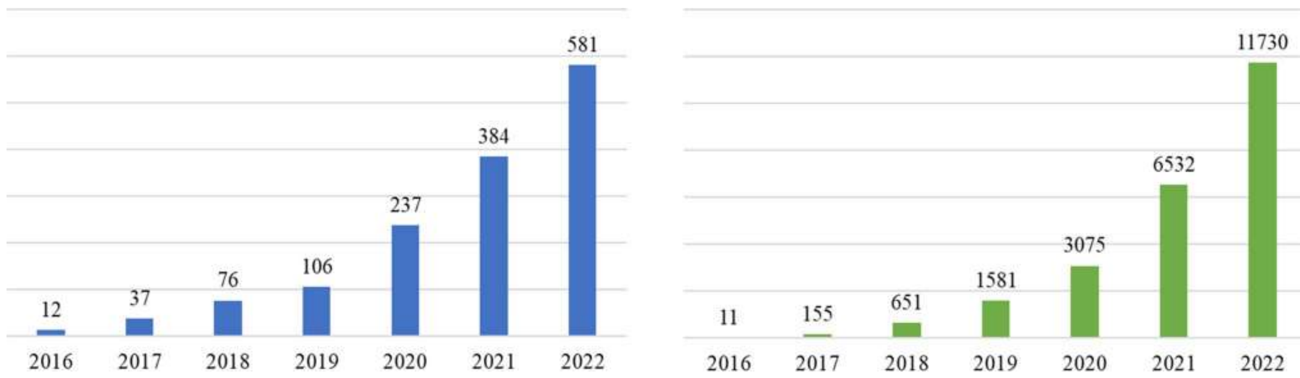



**Fig. 2** Research performance (total publications and total citations)

of academic attention. Additionally, analyzing the publication and citation trends can provide valuable information for researchers, policymakers, and practitioners interested in the field of sustainability and SDGs.

### 3.5 Publications and citations trends

Figure 2 illustrates the substantial growth in total publications (TP) and total citations (TC) between 2016 and 2022, with both metrics experiencing remarkable expansion at an average compound annual growth rate (CAGR) of 71.5%. Notably, significant spikes in growth were observed between 2017 and 2020. An interesting trend emerges as TC outpaces TP in terms of growth rate, indicating that a select number of papers garner a disproportionate share of citations. This phenomenon suggests a growing specialization in the field, where a few highly influential papers dominate citation counts. An in-depth analysis reveals that 79% of publications receive at least one citation each, with 52% of them cited a minimum of 10 times. Impressively, 26 publications stand out by accumulating over 100 citations during the study period.

The significant growth in both total publications (TP) and total citations (TC), along with the evident concentration of citations on a relatively small number of papers, signifies several crucial points. Firstly, it suggests a burgeoning interest in the field of study, indicating the growing importance of research on the topic. Secondly, the concentration of citations reflects a deepening specialization within this field, where a handful of influential papers exert a substantial impact. This could be due to their groundbreaking nature or unique contributions. Furthermore, it highlights the need for researchers to recognize these influential papers, as they are likely to shape and guide future developments in the area. In summation, our exploration of the most cited bibliometric papers has illuminated the growing significance and evolving trends in this field. As literature continues to expand and diversify, it becomes increasingly vital to identify the research hotspots by recognizing the leading authors' affiliating countries and institutions.

### 3.6 Country analysis

Table 6 presents the countries accounting for 92% of the study articles. China tops the table both in TP and TC. Although Spain occupies the second slot on TP, it is replaced by the United Kingdom on TC. Interestingly, the count for TP and TC is comparatively low for India and Malaysia, suggesting future scope for more influential scientometric works on SDGs. The table further suggests a positive correlation between the number of publications and the number of citations among the nations. Countries like China, the United Kingdom, Spain, Italy, Brazil, and Australia have more publications and citations than India, the United States, Portugal, and Malaysia. This might indicate that these countries' research output on the scientometrics of SDGs is relatively higher. Interestingly, the countries with the most publications and citations belong to the Global North, while those with comparatively fewer publications and citations are part of the Global South, which essentially has lower levels of economic development.

A Sankey diagram (as presented in Fig. 3) is a flow diagram often used to visualize the flow of resources through a system. The width of the arrows (or "flows") represents the relative magnitude of the flow, while the height of the rectangles (or "nodes") represents the relative importance of the elements in the system. Based on the height of the rectangles, we observe that publications from countries such as China, Spain, Brazil, and the UK are closely aligned with several SDGs. Looking at the flows, SDG 12 (Responsible Consumption and Production), SDG 11 (Sustainable Cities and Communities), SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 9 (Industry, Innovation, and Infrastructure) have

**Table 6** Top countries

| Country | TP | TC |
|---|---|---|
| China | 323 | 5733 |
| Spain | 202 | 3601 |
| Brazil | 147 | 2049 |
| United Kingdom | 139 | 5445 |
| India | 108 | 961 |
| Italy | 96 | 2061 |
| Australia | 83 | 1778 |
| United States | 79 | 1328 |
| Malaysia | 69 | 1090 |
| Portugal | 66 | 645 |

This table shows the top authors' affiliated countries publishing reviews on SDGs and sustainability. TP = total publications, and TC = total citations on the search date

the most number of publications mapped to them. SDG 16 (Peace, Justice, and Strong Institutions), SDG 17 (Partnerships for the Goals), SDG 10 (Reduced Inequalities), and SDG 5 (Gender Equality) have relatively fewer publications mapped.

The Sankey diagram visually highlights countries like China, Spain, Brazil, and the UK's significant contributions to specific SDGs. It also underscores the prominence of SDGs 12, 11, 7, 13, and 9 while indicating the need for increased research attention to SDGs 16, 17, 10, and 5.

### 3.7 Institution analysis

Table 7 shows the leading authors' affiliated institutions ranked on TP. Our analysis reveals that SDGs and Sustainability authors affiliated with the University of Almeria lead both in TP and TC, followed by the Chinese Academy of Sciences for TP and the Hong Kong Polytechnic University for TC. On closer investigation, we found that the average number of institutions per publication is 2.3, indicating good collaboration among researchers from different institutions. Additionally, authors affiliated with varsities of Global North countries like Spain, Germany, Japan, and Hong Kong exhibit superior performance compared to their counterparts from Global South countries like Brazil, South Africa, and Thailand in terms of both TP and TC.

Conversely, the Sankey diagram depicted in Fig. 4 links the authors' affiliated institutions and SDGs. It is worth mentioning that the University of Almeria in Spain and the Hong Kong Polytechnic University in Hong Kong are associated with all 15 SDGs. Upon closer examination, most publications from top institutions are mapped to SDG 12 (Responsible Consumption and Production), 11 (Sustainable Cities and Communities), and 4 (Quality Education). In contrast, SDG 16 (Peace, Justice, and Strong Institutions), SDG 3 (Good Health and Well-being), SDG 17 (Partnerships for the Goals), SDG 1 (No Poverty), SDG 14 (Life Below Water), SDG 6 (Clean Water and Sanitation), SDG 8 (Decent Work and Economic Growth), and SDG 15 (Life on Land) have fewer publications mapped suggesting scope for future publications.

Following our analysis of the research hotspots, we proceed to discuss the leading outlets publishing bibliometric and scientometric works on SDGs and sustainability.

### 3.8 Journal analysis

Table 8 provides insights into the leading sources publishing scientometric research on SDGs. Our findings suggest that *Sustainability* accounts for the highest number of publications related to SDG research, while the *Journal of Cleaner Production* leads the race with the most citations and average citations. It is also the journal with the highest impact factor, indicating its highly influential stance among peers.

Further, the Sankey diagram presented in Fig. 5 highlights the connection between journals and their respective SDG mappings. Notably, the *Journal of Cleaner Production* and *Sustainability* are mapped to 15 SDGs. Upon closer examination of highly cited journals, SDG 12 (Responsible Consumption and Production), 11 (Sustainable Cities and Communities), and 13 (Climate Action) have the most publications mapped, while SDG 5 (Gender Equality) and 10 (Reduced Inequalities) have relatively fewer publications mapped with the leading journals suggesting scope for future submissions.

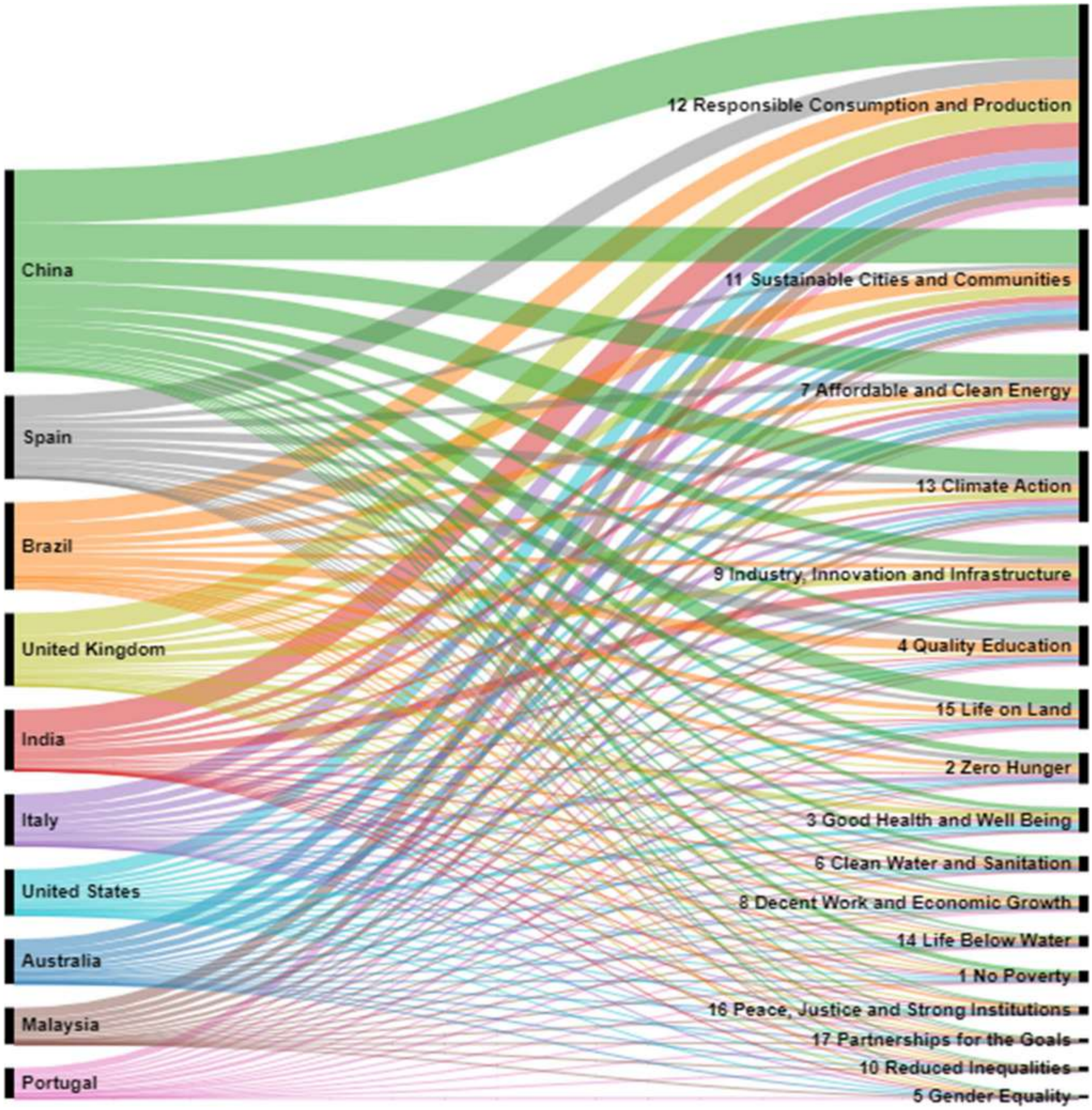



**Fig. 3** Sankey diagram of country analysis

### 3.9 Authorship analysis

Table 9 presents the top authors publishing at least nine survey articles on SDGs, while Table 10 links their most cited publications with SDG(s). Ayyoob Sharifi tops the table with the most publications, while Luis J. Belmonte-Ureña is the most influential with the highest citations. Further analysis of the authorship pattern indicates that only 5% of the study articles are single-authored, while 95% have multiple authors, indicating high levels of collaboration. Among the multi-authored papers, those with three authors are the most common (about 25%), followed by those with two (about 22%). Interestingly, 33 papers (about 2%) have more than ten authors each.

**Table 7** Top authors' affiliated institutions

| Institution | Country | TP | TC |
|---|---|---|---|
| University of Almeria | Spain | 56 | 1689 |
| Chinese Academy of Sciences | China | 39 | 554 |
| University of Johannesburg | South Africa | 28 | 479 |
| Hong Kong Polytechnic University | Hong Kong | 26 | 1147 |
| Mahidol University | Thailand | 21 | 449 |
| Universidade Federal Fluminense | Brazil | 19 | 307 |
| University of Chinese Academy of Sciences | China | 19 | 297 |
| Hamburg University of Applied Sciences | Germany | 18 | 57 |
| Hiroshima University | Japan | 17 | 118 |
| Universidade Estadual de Campinas | Brazil | 17 | 75 |

This table shows the top authors' affiliated institutions publishing reviews on SDGs and sustainability. TP = total publications and TC = total citations on the search date

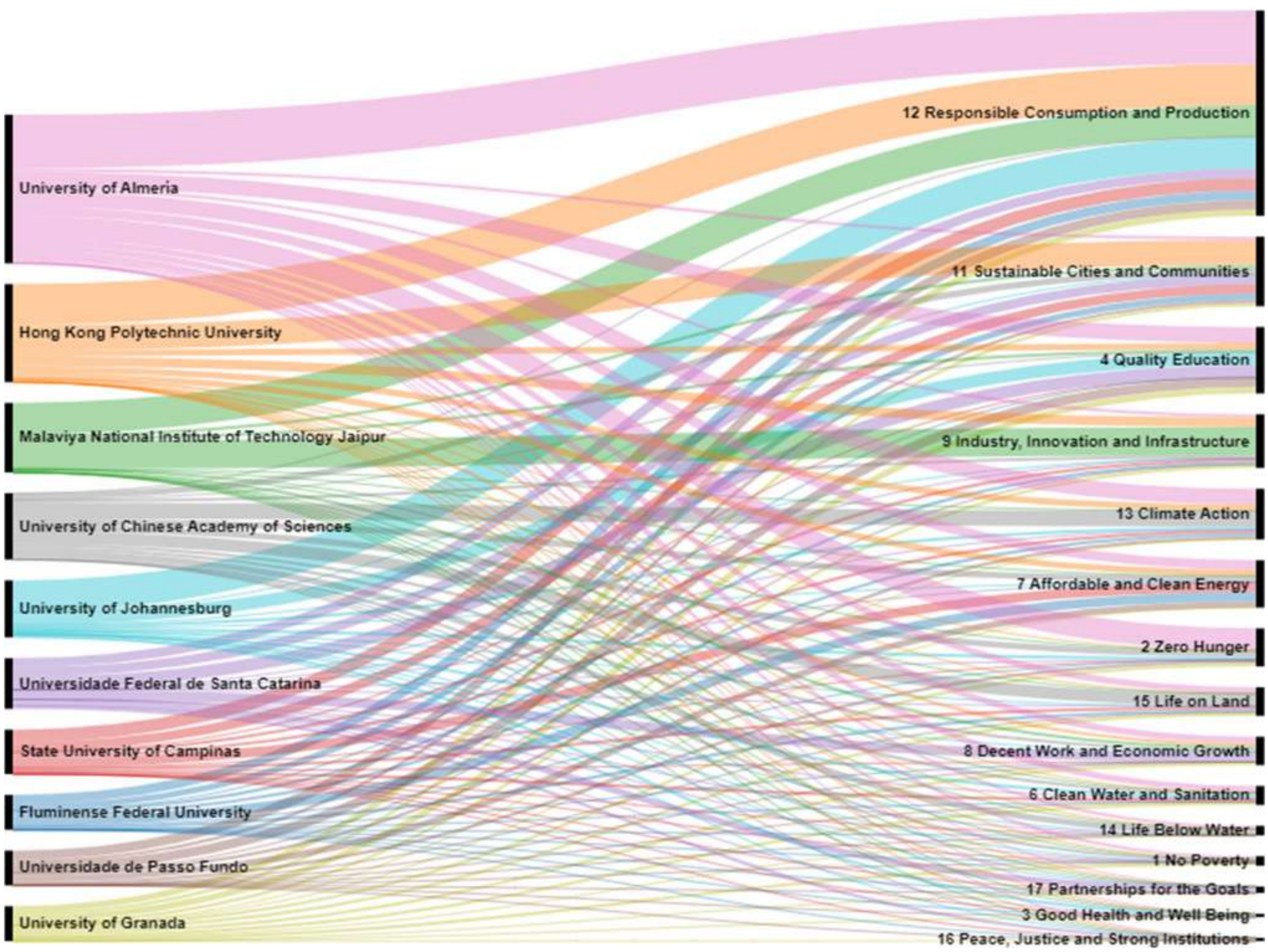



**Fig. 4** Sankey diagram of institutions analysis

**Table 8** Top sources

| Journal Name | TP | TC | TC/TP | IF |
|---|---|---|---|---|
| Sustainability | 303 | 3786 | 12.5 | 3.88 |
| Journal of Cleaner Production | 95 | 7165 | 75.4 | 11.07 |
| Environmental Science and Pollution Research | 41 | 368 | 9.0 | 5.19 |
| International Journal of Environmental Research & Public Health | 41 | 411 | 10.0 | 4.61 |
| Energies | 25 | 266 | 10.6 | 3.25 |
| Environment, Development and Sustainability | 17 | 99 | 5.8 | 4.08 |
| Land | 16 | 97 | 6.1 | 3.90 |
| Water (Switzerland) | 13 | 89 | 6.8 | 3.53 |
| International Journal of Sustainability in Higher Education | 11 | 109 | 9.9 | 2.85 |
| Science of the Total Environment | 11 | 180 | 16.4 | 10.75 |

This table shows the top sources publishing reviews on SDGs and sustainability. TP = total publications, TC = total citations, TC/TP = average citations, and IF = impact factor on the search date

We observe that highly impactful works from leading authors encompass a wide spectrum of topics such as the 'impact of Covid-19 on cities,' 'the significance of agricultural waste,' 'knowledge management in sustainability research and practice,' 'digital transformation in learning,' 'sustainable learning,' 'sustainable land use,' 'Industry 4.0 technologies for circular economic models,' 'cruise tourism research,' and more. Many of these authors have undertaken bibliometric analyses of related topics within one or a few preferred SDGs, while some, possibly bibliometric enthusiasts, have explored diverse topics across multiple SDGs. Although a comprehensive discussion of these contributions is beyond the scope of this analysis, the list of the most significant publications by top productive researchers reveals that SDGs 11, 12, and 4 are each associated with two publications. Given the impact generated by the analysis of these topics, we recommend that bibliometricians and enthusiasts should (i) delve deeper into these areas to uncover new aspects or overlooked dimensions and (ii) explore similar or related topics within SDGs 11, 12, 4, and others. While citations and impact can be strong motivators for research, especially for bibliometric enthusiasts, it is essential to consider the significance of SDGs to humanity. This entails assessing underexplored topics within the most studied SDGs, important aspects within less researched SDGs, and more. Such an approach can provide guidance to mainstream researchers, both academic and industrial, working on these SDGs. For instance, top contributing authors to bibliometric studies on SDGs have not typically focused on the most extensively researched SDGs like SDG 3 (Good health and well-being), 7 (Affordable and clean energy), and 13 (Climate Action), likely due to the sheer volume of associated literature. This represents a significant gap in bibliometric studies on SDGs, which offers substantial opportunities for bibliometric researchers. Therefore, we recommend that bibliometric analysts and enthusiasts embark on more challenging research endeavours, seeking out tools, methods, and approaches to analyze large bodies of literature.

We further analyzed the collaboration patterns among authors and their average impact. Table 11 shows that international collaborations lead the share of total publications (39.1%) and bear the highest average impact (TC/TP: 23.2). Only national collaboration had a share of 26.3% of total publications and a TC/TP ratio of 10.8. Only institutional collaboration had a share of 29.8% of total publications and a TC/TP ratio of 13.6. Single authorship (no collaboration) had the smallest percentage share of total publications at 4.8%, with a TC/TP ratio of 11.5.

### 3.10 Top cited publications and their SDG focus

Table 12 presents the top cited scientometric publications on SDGs and Sustainability. We find that the primary focus areas of the top-cited works are related to themes such as circular economy, green economy, and bio-economy. Interestingly, all of them are highly pertinent to sustainability. Further, the role of supply chain management in sustainability is also evident among the top-cited publications. The increasing application of multiple criteria decision analysis (MCDA) techniques for supply chain management and other similar findings prove to be essential for the growth of supply chain management in a direction aligned with sustainability. However, the under-exploration or neglect of risk factors associated with environmental and social aspects, which form the core sustainability values, is a concern that remains for further exploration.

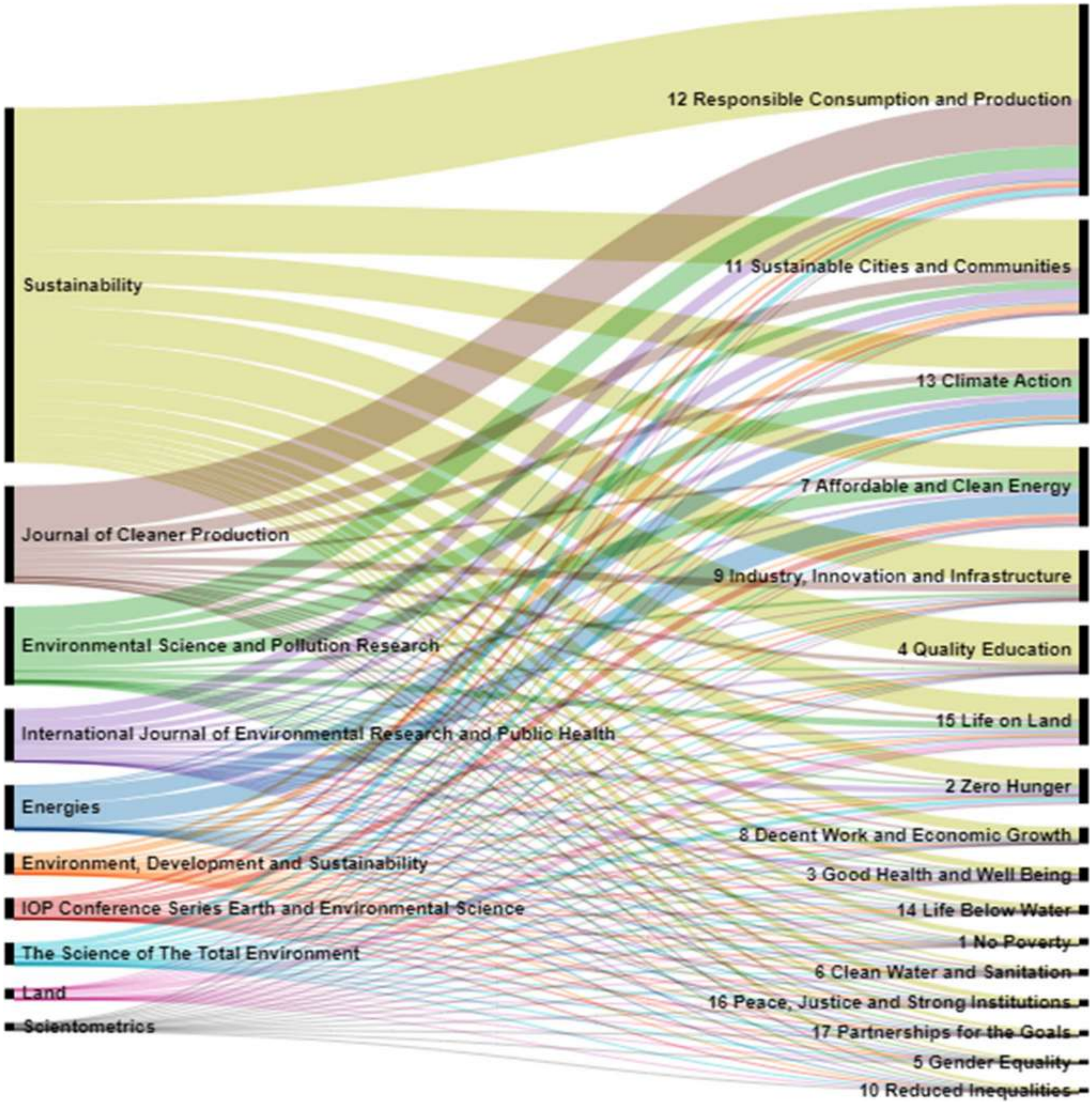



**Fig. 5** Sankey diagram of journals analysis

The top-cited articles include Geissdoerfer et al. [57], who conducted a comprehensive review of the "circular economy," revealing its association with sustainability, emphasizing the circular economy as a prerequisite for sustainability. Cheng [59] presents a holistic literature review on the "sharing economy," focusing on business models, impacts, and sustainable development in tourism and hospitality management, urging a theory-informed research agenda on the sharing economy. D'Amato et al. [58] use machine learning to compare circular, green, and bio-economies, finding that the green economy addresses social and environmental issues more. Olawumi et al. [25] conducted a scientometric review of sustainability research trends, highlighting emerging themes in sustainable urban development, indicators, water management, and environmental assessment. Chen et al. [60] explore the impact of supply chain collaboration on sustainability, noting the need to address social issues in addition to economic and environmental concerns. Huang

**Table 9** Most prolific authors

| Author | Country | TP | TC | TC/TP | h-index |
|---|---|---|---|---|---|
| Ayyoob Sharifi | Japan | 16 | 107 | 6.7 | 31 |
| Luis J. Belmonte-Ureña | Spain | 15 | 715 | 47.7 | 21 |
| Walter Leal Filho | United Kingdom | 13 | 231 | 17.8 | 35 |
| Emilio Abad-Segura | Spain | 11 | 499 | 45.4 | 17 |
| Izabela Simon Rampasso | Chile | 11 | 22 | 2.0 | 12 |
| Rosley Anholon | Brazil | 10 | 26 | 2.6 | 17 |
| Philip Hallinger | Thailand | 10 | 293 | 29.3 | 49 |
| Aznar-Sánchez, José Ángel | Spain | 9 | 369 | 41.0 | 19 |
| Osvaldo Luiz Gonçalves Quelhas | Brazil | 9 | 244 | 27.1 | 21 |
| Alejandro Vega-Muñoz | Chile | 9 | 44 | 4.9 | 13 |

This table shows the top authors publishing the highest number of reviews on SDGs and Sustainability. TP = total publications, TC = total citations, and TC/TP = average citations on the search date

et al. [101] investigate gender differences in productivity and impact in STEM fields, offering insights into t the sustainability of women's careers in academia. Zyoud et al. [61] analyze multiple criteria decision analysis techniques and their applications. Feng et al. [75] delve into corporate social responsibility in supply chain management, identifying research gaps and considering supplier perspectives. Li et al. [102] conducted a bibliometric analysis on coal gangue, highlighting its utilization but noting a lack of research on associated risks. Lastly, Martens et al. [103] study sustainability in project management, identifying key factors like sustainable innovation models, stakeholder management, and environmental policies.

In conclusion, Table 12, along with subsequent content analysis of top-cited works, highlights that six works, specifically those ranked 1, 2, 3, 8, 9, and 10, are closely associated with SDG 12. In contrast, four of the top-cited reviews are intertwined with SDGs 8 and 9, with works 3, 4, 5, and 9 relating to SDG 8 and works 5, 8, 9, and 10 having connections to SDG 9. It's noteworthy that SDGs 3 (Good Health and Well-being) and 7 (Affordable and Clean Energy), despite their prominence, have not been extensively examined using bibliometric methods, likely due to the extensive volume of available literature and potentially limited interest from core journals and research communities in these SDGs. Overcoming these challenges through well-designed bibliometric and scientometric studies in SDGs 3 and 7 holds significant promise, offering valuable insights for researchers and policymakers at various levels. As bibliometric and scientometric studies gain traction in SDGs 12, 8, 9, and related areas, encouraging bibliometricians to apply their innovative methods to these SDGs can greatly contribute to insightful research and informed policymaking processes within these domains. After gleaning insights from the top-cited reviews, we now delve into examining themes related to SDGs and sustainability by analyzing the co-occurrence of keywords.

### 3.11 Keyword co-occurrence analysis and SDG focus

To create the keyword co-occurrence map, we treated all keywords as the unit of analysis and applied the full counting method, setting a threshold of ten occurrences for each keyword. Out of the initial 7,859 keywords, only 192 keywords satisfied the threshold requirement. Figure 6 illustrates these 192 keywords forming four distinct clusters, each represented by a different color – cluster 1 (red), cluster 2 (green), cluster 3 (blue), and cluster 4 (yellow). The size of the circles and texts within each cluster indicates the strength of co-occurrence with other keywords, while the distance between the keywords and the thickness of the lines show the relatedness and linkages between them. Additionally, we analyzed the top 25 keywords in each cluster to determine their corresponding SDG mapping, calculating the percentage of keywords associated with each SDG Goal using SDG Mapper [104].

The keywords in Cluster 1 (see Table 13) exhibit significant links to several SDGs. We find that SDG 12 (Responsible Consumption and Production) has the most substantial relationship with these keywords, followed by SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land). The analysis of these keywords' co-occurrence in various publications indicates a growing concern for environmental sustainability and protection, especially in developing countries.

**Table 10** Most cited publications of the most prolific authors

| Author | Top Article | Bibliometric Technique(s) | SDG Focus |
|---|---|---|---|
| Ayyoob Sharifi | "The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management"[93] | Keyword Co-occurrence analysis | 11 SUSTAINABLE CITIES AND COMMUNITIES |
| Luis J. Belmonte-Ureña | "Agricultural waste: Review of the evolution, approaches, and perspectives on alternative uses"[77] | Co-citation, Co-authorship, Keyword Co-occurrence, Social network analysis | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION<br>2 ZERO HUNGER |
| Walter Leal Filho | "A literature-based review on potentials and constraints in the implementation of the sustainable development goals"[94] | Systematic selection and content analysis | 11 SUSTAINABLE CITIES AND COMMUNITIES<br>17 PARTNERSHIPS FOR THE GOALS |
| Emilio Abad-Segura | "Sustainable management of digital transformation in higher education: Global research trends"[78] | Traditional bibliometrics, Co-citation, Co-authorship, Keyword Co-occurrence analysis | 4 QUALITY EDUCATION |
| Izabela Simon Rampasso | "Knowledge management in the context of sustainability: Literature review and opportunities for future research"[95] | Bibliometrics & content analysis | 4 QUALITY EDUCATION |
| Rosley Anholon | "The role of transformation in learning and education for sustainability"[96] | Qualitative case studies | 4 QUALITY EDUCATION |
| Philip Hallinger | "Bringing context out of the shadows of leadership"[97] | Qualitative analysis | 17 PARTNERSHIPS FOR THE GOALS |
| José Ángel Aznar-ánchez | "Worldwide research trends on sustainable land use in agriculture"[98] | Keyword Co-occurrence analysis | 15 LIFE ON LAND |
| Osvaldo Luiz Gonçalves Quelhas | "Exploring industry 4.0 technologies to enable circular economy practices in a manufacturing context"[99] | Qualitative framework involving literature review | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| Alejandro Vega-Muñoz | "In search of 'a research front' in cruise tourism studies"[100] | Scientific activity life-cycle, impact and relational indicators | 17 PARTNERSHIPS FOR THE GOALS |

This table associates the top-cited SDG(s) and Sustainability reviews of the top authors with the corresponding SDG(s) and indicates the bibliometric technique(s) applied

**Table 11** Effect of collaboration

| Collaboration Type | % Share | TC/TP |
|---|---|---|
| International | 39.1% | 23.2 |
| Only national | 26.3% | 10.8 |
| Only institutional | 29.8% | 13.6 |
| Single authorship (no collaboration) | 4.8% | 11.5 |

The keywords in Cluster 2 (see Table 14) exhibit close associations with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production). Research within this cluster has emphasized the adoption of circular economy models, which encompasses life cycle assessment, waste management, and recycling, to minimize the environmental impact of industries. Furthermore, efficient supply chain management, facilitated by digital technologies and Industry 4.0, has been studied to reduce carbon footprint and promote environmental sustainability, particularly in the construction industry. Findings from this cluster of studies indicate that decision-making processes based on life cycle assessment can effectively promote responsible consumption and production in the context of buildings and construction, contributing to the realization of SDG 9 and SDG 12.

The keywords in Cluster 3, as detailed in Table 15, primarily exhibit connections to SDG 6 (Clean Water and Sanitation) and SDG 7 (Affordable and Clean Energy). Research within this cluster is centered on the development of policies that advance sustainable environmental management and the conservation of water and energy resources. Key focal points include renewable energy, energy efficiency, and the reduction of carbon emissions, all of which play crucial roles in mitigating environmental impacts and fostering sustainable economic development. While these keywords are less strongly associated with SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-being), they are nonetheless vital in comprehending the environmental determinants influencing food production and human health.

The keywords in Cluster 4 (see Table 16) predominantly align with SDG 11 (Sustainable Cities and Communities). Research in this cluster has concentrated on formulating a conceptual framework for urban development that harmonizes environmental sustainability, social inclusivity, and economic growth. Smart cities have emerged as a viable solution for addressing challenges resulting from urbanization, encompassing issues like traffic congestion, air pollution, and waste management. Urbanization and land use changes have also impacted biodiversity, leading to reduced ecosystem services such as clean air and water, pollination, and nutrient cycling. Consequently, prioritizing urban sustainability and biodiversity conservation in developing cities and urban areas is vital to fulfilling the objectives of SDG 11. While these keywords exhibit a weaker connection to SDG 15 (Life on Land), it remains essential to acknowledge the interplay between urban development and biodiversity preservation.

### 3.12 Co-citation map of SDGs

The SDG goals are interdependent, meaning that one goal's achievement depends on the success of the other goals [105]. Using network analysis techniques, Le Blanc [106] demonstrated that SDG connections are somewhat unequal. Some goals have multiple targets connecting them to many other goals, while others have weak connections to the rest of the SDG system. We created a co-citation map (see Fig. 7) to visualize the relationships between different SDGs. The proximity of the SDGs on the map reflects their semantic association, indicating that publications related to those SDGs are often cited together in the same set of publications. The nodes' size represents the SDG frequency in terms of overall publications, while the thickness of the edges shows how often these SDGs are co-cited. Figure 7 displays the SDG map suggesting three clusters.

Cluster 1 (green) has a thematic focus on social development and equality, as it comprises SDG related to education (SDG 4), healthcare (SDG 3), gender equality (SDG 5), poverty reduction (SDG 1), and building peaceful and just societies (SDG 16). The keywords within this cluster may pertain to social inclusion, human rights, access to education and healthcare, and reducing inequalities (SDG 10).

Cluster 2 (red) emphasizes SDG 8 (Decent Work and Economic Growth), SDG 13 (Climate Action), SDG 2 (Zero Hunger), SDG 15 (Life on Land), SDG 6 (Clean Water and Sanitation), and SDG 14 (Life Below Water). This cluster's thematic focus appears to be on environmental sustainability, comprising SDGs related to climate change, land, ocean conservation, and water and food security. The co-occurrence of keywords within this cluster may pertain to sustainable agriculture, responsible consumption and production, water and waste management, and renewable energy.

**Table 12** Top cited review articles

| TC | TC/Year | Author(s) | Title | Search Engine | TAS | Time Period | SDG Focus |
|---|---|---|---|---|---|---|---|
| 2526 | 421.0 | Geissdoerfer et al. [57] | "The circular economy—A new sustainability paradigm?" | Web of Science | 295 | 2006–2016 | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| 506 | 72.3 | Cheng [59] | "Sharing economy: A review and agenda for future research" | Scopus, EBSCO Google Scholar | 162 | 2010–2015 | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| 455 | 75.8 | D'Amato et al. [58] | "Green, circular, bio economy: A comparative analysis of sustainability avenues" | Web of Science | 1943 | 1990–2017 | 4 QUALITY EDUCATION<br>8 DECENT WORK AND ECONOMIC GROWTH<br>12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| 348 | 69.6 | Olawumi et al. [25] | "A scientometric review of global research on sustainability and sustainable development" | Web of Science | 2094 | 1991–2016 | 6 CLEAN WATER AND SANITATION<br>8 DECENT WORK AND ECONOMIC GROWTH<br>11 SUSTAINABLE CITIES AND COMMUNITIES |
| 270 | 45.0 | Chen et al. [60] | "Supply chain collaboration for sustainability: A literature review and future research agenda" | Scopus, Web of Science, and Business Source Premier | 1778 | 1987–2015 | 8 DECENT WORK AND ECONOMIC GROWTH<br>9 INDUSTRY, INNOVATION AND INFRASTRUCTURE<br>16 PEACE, JUSTICE AND STRONG INSTITUTIONS |
| 255 | 85.0 | Huang et al. [101] | "Historical comparison of gender inequality in scientific careers across countries and disciplines" | Web of Science | 865 | 1955–2010 | 5 GENDER EQUALITY<br>10 REDUCED INEQUALITIES |

**Table 12** (continued)

| TC | TC/Year | Author(s) | Title | Search Engine | TAS | Time Period | SDG Focus |
|---|---|---|---|---|---|---|---|
| 244 | 40.7 | Zyoud et al. [61] | "A bibliometric-based survey on AHP and TOPSIS techniques" | Scopus, Web of Science, Google Scholar, PubMed | 10,188 | One time interval (20th April 2016) | 4 QUALITY EDUCATION |
| 225 | 37.5 | Feng et al. [75] | "Corporate social responsibility for supply chain management: A literature review and bibliometric analysis" | Scopus, Google Scholar | 628 | 1997–2017 | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| 223 | 55.8 | Li et al. [102] | "Comprehensive utilization and environmental risks of coal gangue: A review" | WoS, China National Knowledge Internet (CNKI) | 237 | 1992–2018 | 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| 193 | 32.2 | Martens et al. [103] | "Key factors of sustainability in project management context: A survey exploring the project managers' perspective" | – | 199 | 1994–2014 | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |

This table displays the top-cited quantitative review articles on SDGs and Sustainability, aligning them with their respective focused SDG(s). It also provides essential citation metrics, including TC (total citations), TC/Year (average annual citations), and TAS (total articles used for the study)

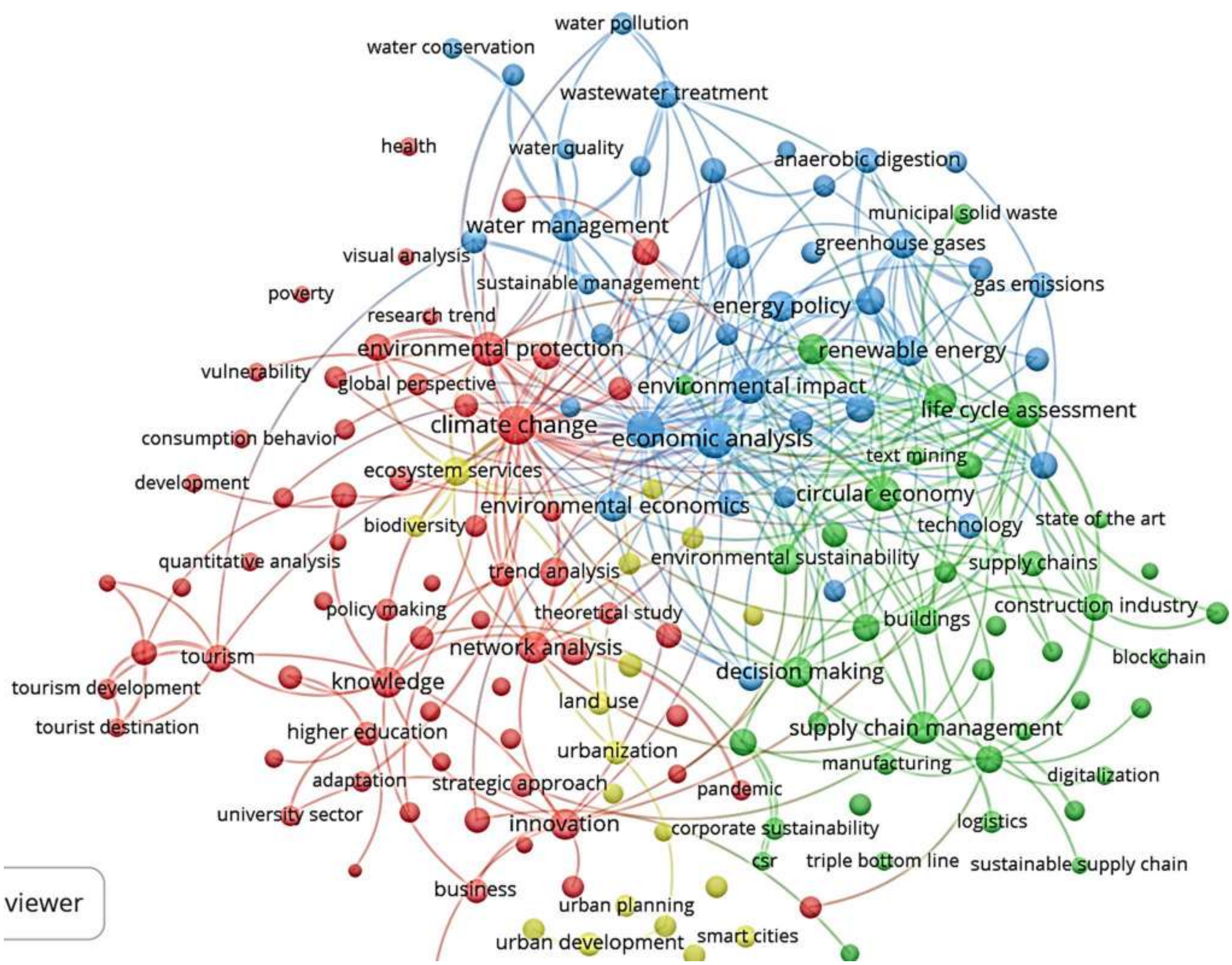
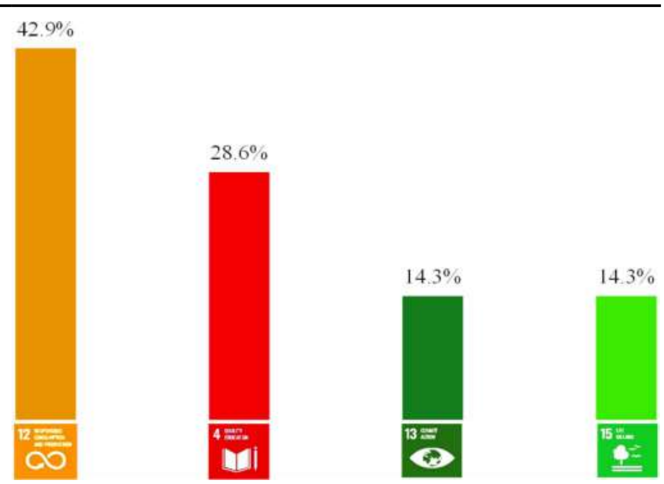



**Fig. 6** Keyword co-occurrence

**Table 13** Cluster 1 keywords' SDG mapping

| Cluster 1 (red) | SDG Mapping |
|---|---|
| Climate change environmental protection network analysis innovation knowledge trend analysis developing countries tourism social networks conservation |   |

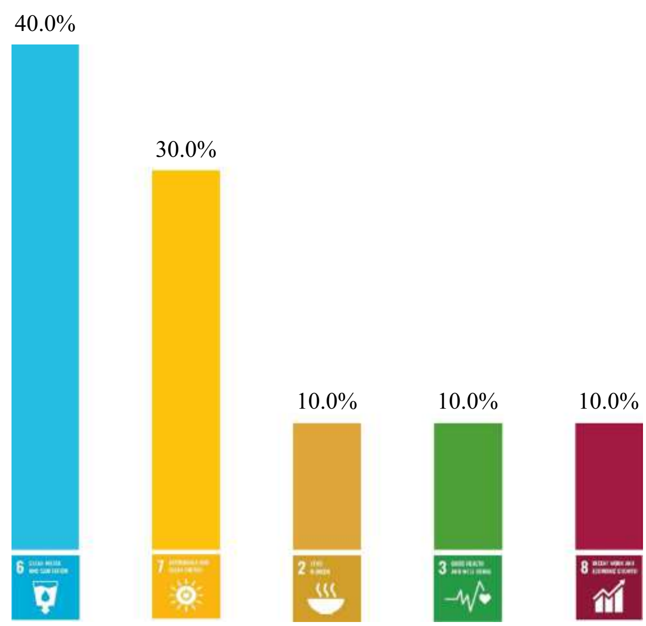
This table correlates the cluster 1 keywords with their corresponding SDGs

**Table 14** Cluster 2 keywords' SDG mapping

| Cluster 2 (green) | SDG Mapping |
|---|---|
| Life cycle assessment circular economy supply chain management waste management decision making recycling environmental sustainability buildings construction industry industry 4.0 |   |

This table correlates the cluster 2 keywords with their corresponding SDGs

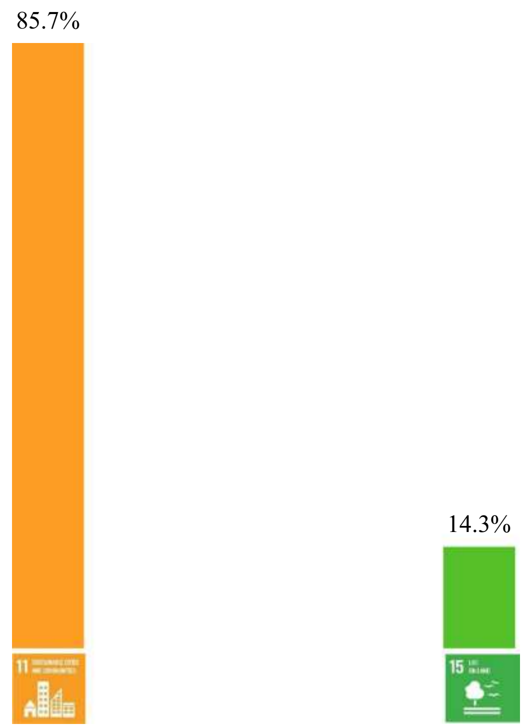
**Table 15** Cluster 3 keywords' SDG mapping

| Cluster 3 (blue) | SDG Mapping |
|---|---|
| Economic analysis environmental management environmental impact water management energy policy renewable energy environmental economics greenhouse gases energy efficiency carbon emission |   |

This table correlates the cluster 3 keywords with their corresponding SDGs

Cluster 3 (blue) focuses on SDGs 12 (Responsible Consumption and Production), SDG9 (Industry, Innovation, and Infrastructure), SDG7 (Affordable and Clean Energy), and SDG11 (Sustainable Cities and Communities). This cluster's thematic focus appears to be sustainable urbanization, infrastructure development, and energy consumption. The co-occurrence of keywords within this cluster may pertain to the circular economy, green technology, energy efficiency, and sustainable transportation.

**Table 16** Cluster 4 keywords' SDG mapping

| Cluster 4 (yellow) | SDG Mapping |
|---|---|
| Ecosystem services urbanization urban development land use conceptual framework smart cities biodiversity cities urban area urban sustainability |   |

This table correlates the cluster 5 keywords with their corresponding SDGs

The co-citation map of SDGs has provided us with valuable insights into the semantic associations and connections between these goals. As we delve into the realm of social network analysis (SNA) to investigate the linkages among these SDGs, we will uncover a deeper layer of their interdependence and the roles they play in shaping sustainable development. This analysis will offer a more comprehensive view of how these goals interact and influence one another, contributing to our understanding of the dynamic nature of SDGs and their significance in driving global sustainability.

### 3.13 Social network analysis (SNA) of SDG linkages

Our study uniquely incorporates Social Network Analysis (SNA) to understand the interconnected nature of SDGs [106]. For analyzing the network of SDGs, we used "SDGToolkit" to construct an SDG network focusing on metrics such as eigenvector and betweenness centrality parameters. We utilized output files generated by VOSviewer, including the map file delineating item weights and the network file indicating link strengths between the items, as the input for SDGToolkit's subsequent analyses [107–109] The betweenness centrality of an SDG node measures its significance as a connecting point in the flow of information within the network. This is calculated by counting how often the node lies on the shortest path between two other SDG nodes. An SDG node with high betweenness centrality serves as a bridge between different sections of the network. Eigenvector centrality is another social network analysis metric that measures a node's influence within a network [110]. It considers the number of connections a node has and the centrality of its connected nodes. In other words, the importance of a node is determined by the number of important nodes it is connected to SDG nodes with high eigenvector centrality in SDG networks will be regarded as key centers of attention.

Figure 8a illustrates that SDG 8 (decent work and economic growth), SDG 7 (affordable and clean energy), and SDG 12 (responsible consumption and production) have the highest eigenvector centrality values, indicating that they are the network leaders. Figure 8b, on the other hand, presents an SDG network based on betweenness centrality. The thickness of the links between the two goals on the map represents the strength of the connection between SDGs. The strongest links are observed between SDG 9 and SDG12 (industry and consumption), SDG 8 and SDG12 (work and consumption), and SDG 8 and SDG13 (work and climate). The network emphasizes the central role of SDGs 8, 9, 12, and 13 in the network.

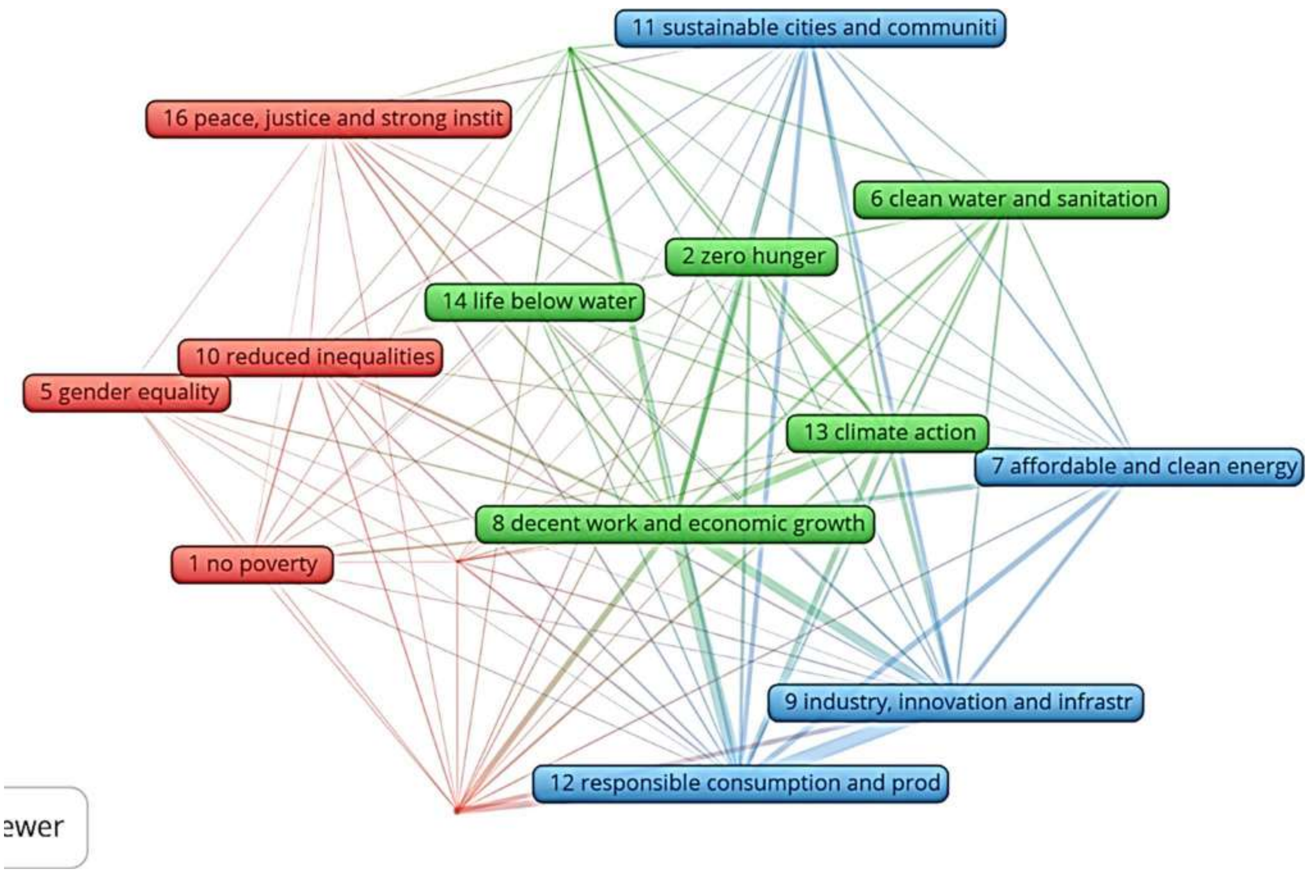



**Fig. 7** Co-citation map of SDGs

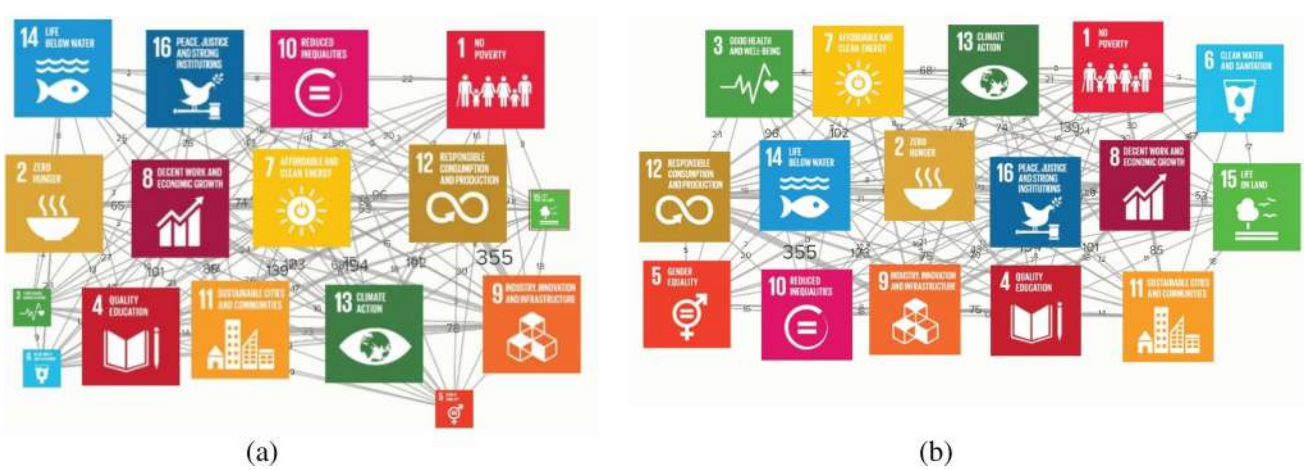


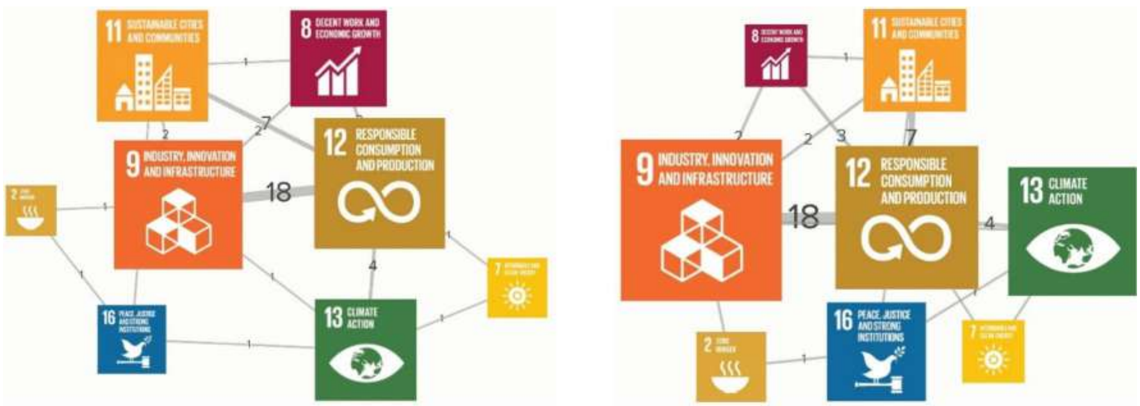

**Fig. 8** **a** SNA of SDGs based on eigenvector centrality. **b** SNA of SDGs based on betweenness centrality

As we gain a deeper understanding of the SNA of SDG linkages, we move forward to examine how different Fields of Research (FoRs) connect with these SDGs. This exploration will provide valuable insights into the multidisciplinary and interdisciplinary nature of SDGs, shedding light on the various research domains contributing to the achievement of these global objectives.

**Table 17** Top field of research (FoR)

| Field of Research | TP | TC | TC/TP |
|---|---|---|---|
| Library and Information Studies | 145 | 1374 | 9.48 |
| Strategy, Management and Organisational Behaviour | 84 | 767 | 9.13 |
| Environmental Management | 74 | 659 | 8.91 |
| Building | 39 | 458 | 11.74 |
| Marketing | 34 | 230 | 6.76 |

This table compares the top fields of research based on total publications (TP), total citations (TC), and average citations (TC/TP)



(a) (b)

**Fig. 9** **a** SNA of Library and Information Studies based on eigenvector centrality. **b** SNA of Strategy, Management, and Organizational Behaviour based on eigenvector centrality

### 3.14 Fields of research (FoRs) and their SDG linkages

Table 17 compares the top five FoR categories based on their total publications (TP), total citations (TC), and average citations (TC/TP). Library and Information Studies leads with the highest number of total publications (145) and total citations (1374). Its substantial average citations of 9.48 underscore the significant influence and impact of research in this field on the academic community. The field of Building boasts the highest average citations at 11.74 and the second-highest total citations (458), indicating a substantial level of impact and relevance in its research. Marketing, with a slightly lower average citation rate of 6.76 and the lowest total citations (230), still maintains a noteworthy level of influence. Strategy, Management and Organizational Behaviour, along with Environmental Management fields, display similar average citation rates, suggesting that research in these fields also renders substantial impact.

We employed SNA to delve further into the top two FoRs, namely Library and Information Studies and Strategy, Management, and Organizational Behaviour, based on TP and TC. In the case of Library and Information Studies, Fig. 9a depicts SDG 11 as the leader within the network, boasting the highest eigenvector centrality value. It's followed by SDG 13, SDG 12, and SDG 15, which also wield significant influence. Figure 9b displays the SDGs exhibiting the highest betweenness centrality, with thicker links indicating stronger connections between these SDGs. The most robust links are observed between SDG 4 and 14 (Energy and Climate), SDG 9 and 12 (Industry and Consumption), and SDG 11 and 12 (Cities and Consumption).

As for the Field of Research, Strategy, Management, and Organisational Behaviour, Fig. 10a underscores the centrality of SDG 12. Figure 10b provides a network map of SDGs based on SNA centrality measures. Analyzed in terms of eigenvector centrality, SDG 9 (Industry) and SDG 12 (Consumption) exhibit high centrality. This suggests that these SDGs are not only pivotal to the research within this field but are closely connected to other highly relevant SDGs, forming a cohesive group in the network of relationships between different SDGs and research topics. Additionally, SDG 9 (Industry), SDG 12

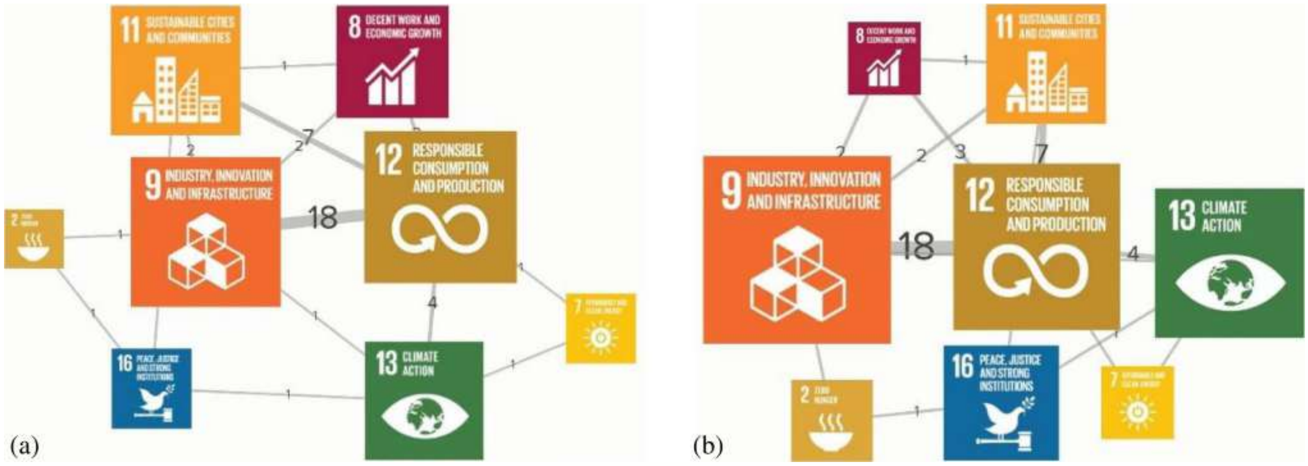



**Fig. 10** **a** SNA of Library and Information Studies based on betweenness centrality. **b** SNA of Strategy, Management, and Organizational Behaviour based on betweenness centrality

**Table 18** Top prominence topics

| Prominence percentile | Topic |
|---|---|
| 99.979 | Sustainability reporting and global reporting initiative |
| 99.942 | Cause-related marketing and corporate social responsibility |
| 99.933 | Green supply chain, environmentally preferable purchasing, and green practices |
| 99.657 | Education for sustainability and higher education institutions |

This table exhibits the top emerging research topics based on their prominence percentile score in Scopus

(Consumption), and SDG 13 (Climate) show high betweenness centrality, indicating their substantial influence in shaping the research agenda within this field. These SDGs occupy central positions in the network of relationships between various SDGs. The most substantial link is between SDG 9 and 12, signifying the interconnection between industry and consumption.

## 4 Emerging research topics and their SDG focus

This study's findings propose various areas for additional investigation. We identified future research topics by utilizing the prominence percentile obtained from SciVal, a database mining tool in Scopus (see Table 18). The momentum of a field, represented by prominence, serves as the basis for ranking these topics.

### 4.1 Sustainability reporting and global reporting initiative

Sustainability reporting [111] and the Global Reporting Initiative (GRI) framework can play a critical role in achieving the United Nations' Sustainable Development Goals (SDG) by allowing companies to measure, disclose and be accountable for their economic, social, and environmental performance. Highly cited articles on this topic are shown in Table 19. The GRI framework, a widely used standard for sustainability reporting, aligns the company's sustainability reporting with the SDG and provides transparent and comparable information about their performance on issues related to the SDG such as SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Sustainability reporting and the GRI framework also support companies in identifying and managing risks and opportunities related to the SDG, setting targets, and measuring progress toward achieving the SDG. In addition to GRI, other reporting frameworks such as the Sustainability Accounting Standards Board (SASB), Integrated Reporting (IR), and the Carbon Disclosure Project (CDP) also contribute to harmonizing corporate sustainability reporting with SDGs, thereby broadening the scope and impact of these initiatives.

**Table 19** Topic: sustainability reporting, global reporting initiative

| TC | Author(s) | Title | Journal | SDG |
|---|---|---|---|---|
| 119 | Pizzi et al. [87] | "Management research and the UN sustainable development goals (SDGs): A bibliometric investigation and systematic review" | Journal of Cleaner Production | 4 QUALITY EDUCATION<br>8 DECENT WORK AND ECONOMIC GROWTH<br>10 REDUCED INEQUALITIES |
| 76 | Mura et al. [74] | "The evolution of sustainability measurement research" | International Journal of Management Reviews | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE<br>12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| 64 | Rodrigues et al. [112] | "Mapping of the literature on social responsibility in the mining industry: A systematic literature review" | Journal of Cleaner Production | 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |

This table discloses the top three reviews and their SDG mapping concerning Sustainability Reporting and Global Reporting Initiatives

Within the realm of sustainability reporting and the Global Reporting Initiative (GRI), Pizzi et al. [87] review investigates the impact of the Sustainable Development Goals (SDGs) on business organizations. Through bibliometric and systematic literature review methods, this study examines 266 publications from leading journals published between 2012 and 2019, revealing four primary research themes related to SDGs: technological innovation, firms' contributions in developing countries, non-financial reporting, and education for SDGs, mapping primarily to SDGs 4, 8, and 12. Similarly, Mura et al. [74] study focuses on sustainability measurement, categorizing it into eight main areas and 12 sub-fields through bibliometric analysis, aligning with SDGs 9 and 12, and emphasizing the importance of common metrics and stakeholder perspectives. In the mining industry, Rodrigue et al. [112] systematic literature review and bibliometric analysis highlight the growing interest in social responsibility, specifically in terms of relationships with local communities and CSR reporting. This research contributes to the understanding of the mining sector's commitment to social responsibility and its alignment with SDGs 4, 8, and 12.

### 4.2 Cause-related marketing and corporate social responsibility

Cause-related marketing and corporate social responsibility (CSR) contribute to achieving the United Nations' Sustainable Development Goals (SDG) by raising awareness and funds for causes, improving social and environmental impact, and integrating social, environmental, and economic considerations into the company's operations. Highly cited articles on this topic are shown in Table 20. By implementing cause-related marketing, companies can contribute to SDG 1 (No Poverty) and SDG 3 (Good Health and Well-being). By implementing CSR, companies can contribute to SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 16 (Peace, Justice, and Strong Institutions). Additionally, by supporting sustainable development through their supply chain and procurement practices, companies can contribute to achieving SDG 12 (Responsible Consumption and Production) and SDG 15 (Life on Land).

In the context of corporate social responsibility (CSR) and its connection to sustainable development (SD), Ye et al. [113] conducted a comprehensive bibliometric analysis. This study, in alignment with SDGs 8, 9, and 12, revealed that CSR's relationship with SD is a burgeoning topic, evidenced by a growing body of literature within leading journals and contributions from key authors. The co-author networks appeared fragmented, and the study identified 11 clusters of concern, with "stakeholder" and "NGO" being consistent themes. Additionally, the research frontier was marked by "climate change" as a new but particularly prominent focus, showcasing the evolving dynamics in this field. Simultaneously, Sarkar et al. [114] explored the evolving landscape of corporate social responsibility (CSR) by analyzing 110 definitions spanning the years from 1953 to 2014. Their approach involved co-word analysis to map key terms, their centrality, and interrelationships. This study, in alignment with SDG 12, discerned six recurring dimensions underlying the CSR concept: economic, social, ethical, stakeholders, sustainability, and voluntary. The analysis offered a new, comprehensive definition of CSR, capturing all these dimensions and providing an objective perspective that complements previous qualitative bibliometric analyses of CSR. Furthermore, Abad-Segura et al. [115] conducted a bibliometric analysis spanning 2001–2018, focusing on the relationship between corporate social responsibility (CSR) and sustainability, which strongly aligns with SDGs 4, 9, and 12. The study revealed a growing interest in this field, mainly within the category of Business, Management, and Accounting, with prominent contributions from journals like the Journal of Business Ethics and Sustainability. The most productive authors, institutions, and countries were identified, with the United States leading in publications and citations. This analysis also indicated a rising trend in global research in recent years.

### 4.3 Green supply chain, environmentally preferable purchasing, and green practices

Table 21 unveils the top-cited reviews related to green supply chains, environmentally preferable purchasing (EPP), and green practices. When organizations adopt green supply chain management, they can lower the environmental impact of their operations, enhance energy efficiency, and encourage sustainable consumption and production. These efforts directly support SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Similarly, implementing EPP as a strategy for procuring environmentally friendly products allows organizations to shrink their carbon footprint, conserve vital natural resources, and endorse eco-friendly alternatives, thereby advancing SDG 12. Green practices, on the other hand, encompass a range of actions such as, reduction in water consumption, recycling, and adoption of energy-efficient technologies. These measures significantly contribute to the realization of SDG 12 and SDG 13.

**Table 20** Topic: cause-related marketing and corporate social responsibility

| TC | Author(s) | Title | Journal | SDG |
|---|---|---|---|---|
| 92 | Ye et al. [113] | "A bibliometric analysis of corporate social responsibility sustainable development in sustainable development" | Journal of Cleaner Production |   |
| 88 | Sarkar et al. [114] | "Zeitgeist or chameleon? A quantitative analysis of CSR definitions" | Journal of Cleaner Production |   |
| 75 | Abad-Segura et al. [115] | "The sustainable approach to corporate social responsibility: A global analysis and future trends" | Sustainability (Switzerland) |   |

This table discloses the top three reviews and their SDG mapping concerning Cause-Related Marketing and Corporate Social Responsibility

**Table 21** Topic: green supply chain, environmentally preferable purchasing, and green practices

| TC | Author(s) | Title | Journal | SDG |
|---|---|---|---|---|
| 270 | Chen et al. [60] | "Supply chain collaboration for sustainability: A literature review and future research agenda" | International Journal of Production Economics | 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 16 PEACE, JUSTICE AND STRONG INSTITUTIONS |
| 224 | Feng et al. [75] | "Corporate social responsibility for supply chain management: A literature review and bibliometric analysis" | Journal of Cleaner Production | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION |
| 174 | Dos et al. [82] | "The analytic hierarchy process supporting decision making for sustainable development: An overview of applications" | Journal of Cleaner Production | 8 DECENT WORK AND ECONOMIC GROWTH |

This table discloses the top three reviews and their SDG mapping concerning Green Supply Chain, Environmentally Preferable Purchasing, and Green Practices

New technology is driving change in business strategies and increasing production and process innovation possibilities, particularly in supply chain collaboration for sustainability. Research explores the links between sustainability collaboration and company performance on economic, environmental, and social metrics. A thorough examination of Table 21 reveals that Chen et al. [60], a systematic literature review and bibliometric analysis mapped to SDG 8, 9, and 16, found that research on supply chain collaboration for sustainability is increasing but lacks attention to social considerations and horizontal collaboration partners. Further, research on corporate social responsibility (CSR) in supply chain management (SCM) has also increased recently. Mapped to SDG 9 and SDG 12, the study by Feng et al. [75] aims to systematically evaluate CSR knowledge structure and progress for SCM through bibliometric analysis and network analysis of 628 peer-reviewed publications. Results show that theoretical and conceptual research dominates the field, focusing on sustainable development and economic and social effects. Research gaps include a lack of practical and normative modelling and a lack of consideration for suppliers in emerging economies. Appearing third in the table, Dos et al. [82], mapped to SDG 8, conducted a systematic literature review on using the analytic hierarchy process in decision-making for sustainable development. It analyzes 173 manuscripts published between 2014 and 2018 from Web of Science, Scopus, and Science Direct databases. The study aims to identify gaps and future research pathways in using the analytic hierarchy process for sustainable development.

### 4.4 Education for sustainability and higher education institutions

Education for sustainability in higher education institutions can play a crucial role in achieving the SDG by providing students with knowledge, skills, and values, incorporating sustainable practices into their operations, and carrying out research and innovation in sustainable development. Table 22 shows the highly cited reviews on this topic. By providing education for sustainability, higher education institutions empower students to become responsible citizens and active agents of change in their communities and thus contribute to SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). By incorporating sustainable practices, research and innovation, they can help reduce environmental impact, address some pressing environmental and social challenges, and lead by example to achieve SDG 12 (Responsible Consumption and Production).

The comprehensive analysis in Table 22 reveals significant developments in both Higher Education for Sustainable Development (HESD) and Education for Sustainable Development (ESD) research. In the case of HESD, Hallinger et al. [62] conducted a highly cited bibliometric review, analyzing 1,459 Scopus-indexed documents. This study highlighted a rapidly growing knowledge base, primarily originating from developed societies, identifying key authors, core journals, and three research clusters. It serves as a benchmark for future HESD research, offering guidance to scholars and aligning with SDGs 4 and 12. Concurrently, Grosseck et al. [116] conducted a bibliometric analysis of 1,813 papers on ESD between 1992 and 2018, illustrating the field's growth, international collaboration, and core research directions in alignment with SDGs 4 and 12. Furthermore, Avelar et al. [117] systematically reviewed the literature on education for advancing the implementation of SDGs, examining 193 publications in the Web of Science. This research identified networks of co-authorship, themes, institutions, and countries and highlighted four dominant thematic lenses supporting the integration of sustainability, ethics, and responsible management education in higher education to promote sustainable development through SDGs 4, 8, and 12.

## 5 Conclusions

The declaration of SDGs represents one of the most visionary actions in the history of the United Nations. Although awareness about SDGs existed before this declaration, it instilled a renewed sense of direction and course of action for national policymakers and other critical stakeholders, including research communities in academia and industry. In response, various scholarly databases mapped scientific publications before and after this declaration to the 17 SDGs as they found relevant. Consequently, the literature related to SDGs has amassed to an enormous volume, and the difficulty in analyzing it using traditional and systematic methods is increasing daily. Fortunately, numerous literature analyses of SDGs have been conducted using bibliometric and scientometric methods. As bibliometrics matures as a field, boasting many useful methods and tools, and continues to evolve, these studies are anticipated to provide vital insights for policymakers and other stakeholders. However, it is crucial to determine the extent to which each SDG has been studied and analyzed through the lens of bibliometric and scientometric research. Such exploration will reveal gaps

**Table 22** Topic: education for sustainability and higher education institutions

| TC | Authors | Title | Journal | SDG |
|---|---|---|---|---|
| 101 | Hallinger et al. [62] | "A bibliometric review of research on higher education for sustainable development, 1998–2018" | Sustainability (Switzerland) |  |
| 56 | Grosseck et al. [116] | "Education for sustainable development: Evolution and perspectives: A bibliometric review of research, 1992–2018" | Sustainability (Switzerland) |  |
| 54 | Avelar et al. [117] | "Education for advancing the implementation of the Sustainable Development Goals: A systematic approach" | International Journal of Management Education |  |

This table discloses the top three reviews and their SDG mapping concerning Education for Sustainability and Higher Education Institutions in the existing bibliometric and scientometric literature analyses on SDGs. To address this, we attempted a bibliometric and scientometric analysis of existing bibliometric and scientometric analyses of SDGs.

Our first research question delves into the research trends discerned through bibliometric and scientometric studies concerning SDGs. It's apparent that the total publications in this domain have experienced substantial growth, with a compound annual growth rate (CAGR) of 74% between 2016 and 2022. Even more striking is the increase in total citations, which have surged at a CAGR of 171% during the same period. These statistics underscore the rapid expansion and growing attention garnered by bibliometric studies on SDGs within the research community. Notably, our analysis identifies the leading contributing countries in quantitative reviews on SDGs, with China, Spain, Brazil, the United Kingdom, and India standing out. In terms of institutions, universities based in Spain, China, South Africa, Hong Kong, and Thailand claim top positions in our study.

In addressing our second research question, we've uncovered significant findings regarding the relationship between various bibliometric studies and different SDGs. Firstly, we have determined that SDG 12 emerges as the most extensively researched SDG across both Web of Science and Scopus. Notably, it ranks highest among article types, encompassing research and review articles. Moreover, SDG 12 is also the most prevalent in bibliometric studies at both the country and institutional levels. Our analysis further reveals that the journals most prolific in publishing bibliometric studies on SDGs are Sustainability and the Journal of Cleaner Production. These journals exhibit a strong predilection for publications related to SDGs 12, 11, 13, and 7. Lastly, our examination highlights the top 10 authors who exhibit a strong publishing presence related to SDG 12.

Pursuant to our third research question, we scrutinized the premier fields of research and assessed the burgeoning topics in this research domain. Our examination of the SDG connections within crucial FoRs highlights SDGs 12 and 11 as the most prominently researched SDGs across various fields. Within the top two most-researched FoRs, SDG 4 claims the top spot in terms of betweenness and eigenvector scores. Notably, SDG 5 and SDG 15 also exhibit significance in the fields of 'Library and Information Studies' and 'Strategy, Management, and Organizational Behavior,' respectively. Furthermore, our analysis delves into the most significant themes emerging in bibliometric examinations of the SDGs. We employ keyword co-occurrence and content analysis of top-cited publications within this timeframe.

Notably, themes related to environmental protection, industries such as tourism, circular economy, life cycle assessment, supply chain management, and waste management feature prominently. These thematic clusters are largely dominated by studies associated with SDG 12. A substantial cluster also encompasses themes like environmental management, renewable energy, and energy policy, with SDG 6 at the forefront. A smaller cluster, conversely, centers around urbanization and its aspects, predominantly under SDG 11. Content analysis offers deeper insights into the role of the circular economy, waste management, and the challenges entailed in operationalizing the SDGs. Some bibliometric studies spotlight the significance of knowledge management practices at the governance and management level for SDG accomplishment. These trending subjects provide ripe opportunities for researchers both in academia and industry, including those specialized in scientometrics and bibliometrics.

Moreover, our network analysis aimed at identifying SDG linkages formed through bibliometric studies underscores that SDGs 12 and 9 exhibit robust connections with most other SDGs, underscoring their pivotal roles in achieving a sustainable future. However, alternative social network analysis (SNA) indicators such as eigenvector and betweenness metrics reveal that SDGs 8, 16, and 17 possess higher scores than SDG 12. This indicates their substantial potential to influence the realization of other SDGs.

A salient observation emerges when we contrast mainstream SDG research, which predominantly focuses on SDGs 3 and 7, with bibliometric analyses. In this context, bibliometric research doesn't emphasize these SDGs to the same extent. Challenges include the sheer volume of publications linked to these SDGs and the complexity of comprehending medical and health-related publications (SDG 3) and technical literature (SDG 7). Specifically, concerning SDG 7, journals like Sustainability and the Journal of Cleaner Production can be targeted since they frequently accommodate bibliometric studies. Nevertheless, addressing the case of SDG 3 poses more complex challenges in terms of identifying suitable outlets. Despite these obstacles, conducting bibliometric studies on SDGs 3, 7, and 13 can be highly rewarding if the unique challenges they pose are effectively addressed.

Further, we recommend that bibliometric researchers explicitly declare the use of Systematic Literature Review (SLR) protocols when assessing SDG literature through bibliometric means. This transparent declaration enhances the rigour and reproducibility of research. Moreover, considering the feasibility, exploring the use of multiple protocols can provide a more comprehensive view of the field. Additionally, we encourage scholars to expand their methodological horizons. Instead of relying solely on 'easy-to-use' or 'convenient' tools and approaches, the field would greatly benefit from the exploration of sophisticated bibliometric tools, methods, and approaches. This broader toolkit can yield deeper insights and enhance the quality of bibliometric studies. Lastly, beyond quantitative methods and tools, we urge researchers to consider the utilization of qualitative and mixed methods. These approaches can offer valuable context and nuance, contributing to a more comprehensive understanding of the SDG literature.

This study's findings significantly contribute to the academic understanding of Sustainable Development Goals (SDGs) research, particularly in bibliometric studies. The observed compound annual growth rate (CAGR) of 74% in publications highlights an escalating academic interest in SDGs. Notably, the predominance of SDG 12 in research outputs and its extensive coverage across diverse article types and journals showcases an academic inclination towards environmental sustainability topics. The findings also reveal significant intersections between different SDGs and fields of research. Furthermore, the study's methodological advancements, such as social network analysis, set new standards for future research. The study's findings also have significant practical implications for policymakers, industry leaders, and practitioners involved in the implementation of SDGs. Industries such as tourism, circular economy, life cycle assessment, supply chain management, and waste management are identified as key areas where SDG research can be translated into practical solutions. The study also highlights the pivotal role of knowledge management in achieving SDGs, suggesting that effective governance and management practices are crucial for SDG accomplishment.

Finally, no matter how rigorous a study is, it inevitably carries some limitations. The primary constraint of this research pertains to its use of Scopus as the primary source for bibliographic data and SciVal for SDG mapping. Expanding the scope to encompass additional data sources could potentially yield different results, thus warranting further reviews with similar objectives in the future.

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**Data availability** All data generated or analysed during this study are included in this published article.

**Code availability** Not Applicable.

## Declarations

**Ethics approval and consent to participate** This article does not contain any studies with human participants performed by any of the authors.

**Informed consent** This article does not contain any studies with human participants performed by any of the authors.

**Competing interests** The author(s) declare no competing interests.



## References

1. Campagnolo L, Davide M. Can the Paris deal boost SDGs achievement? An assessment of climate mitigation co-benefits or side-effects on poverty and inequality. World Dev. 2019;122:96–109. https://doi.org/10.1016/J.WORLDDEV.2019.05.015.
2. Sebhatu SP, Enquist B. Values and multi-stakeholder dialog for business transformation in light of the UN sustainable development goals. J Bus Ethics. 2022;180(4):1059–74. https://doi.org/10.1007/S10551-022-05195-X/FIGURES/3.
3. Dörffel C, Freytag A. The poverty effect of democratization. World Dev. 2023;165: 106186. https://doi.org/10.1016/J.WORLDDEV.2023.106186.
4. Amornkitvikai Y, Pholphirul P. Business productivity and efficiency from aligning with sustainable development goals: empirical evidence from ASEAN manufacturing firms. Bus Strategy Dev. 2023;6(2):189–204. https://doi.org/10.1002/BSD2.233.
5. DasGupta R, Kumar S, Pathak R. Multinational enterprises' internationalization and adoption of sustainable development goals. Int J Manag Fin. 2022;18(4):617–38. https://doi.org/10.1108/IJMF-09-2021-0416/FULL/PDF.

6. Virmani N, Saxena P, Raut RD. Examining the roadblocks of circular economy adoption in micro, small, and medium enterprises (MSME) through sustainable development goals. Bus Strategy Environ. 2022;31(7):2908–30. https://doi.org/10.1002/BSE.3054.
7. Vieira Da Silva CR, Rodrigues AS, Dias PC. 2030 Sustainable Development Goals and higher education: A digital experience in the context of the Interdisciplinary Service-Learning. In: ACM international conference proceeding series; 2022. p. 588–90. https://doi.org/10.1145/3560107.3560204.
8. Awogbemi O, Von Kallon DV. Achieving affordable and clean energy through conversion of waste plastic to liquid fuel. J Energy Inst. 2023;106: 101154. https://doi.org/10.1016/J.JOEI.2022.101154.
9. Cirone F, et al. A sustainability scoring system to assess food initiatives in city regions. Sustain Prod Consum. 2023;36:88–99. https://doi.org/10.1016/J.SPC.2022.12.022.
10. Liu Q, et al. A review of model-based scenario analysis of poverty for informing sustainability. Environ Sci Policy. 2022;137:336–48. https://doi.org/10.1016/J.ENVSCI.2022.09.005.
11. Raman R, Nair VK, Prakash V, Patwardhan A, Nedungadi P. Green-hydrogen research: what have we achieved, and where are we going? Bibliometrics analysis. Energy Rep. 2022;8:9242–60. https://doi.org/10.1016/J.EGYR.2022.07.058.
12. van der Poll HM. The barriers and drivers of environmental management accounting practices' adoption in developed and developing countries for sustainable development. Sustain Dev. 2022;30(5):1222–34. https://doi.org/10.1002/SD.2312.
13. Setioningtyas WP, Illés CB, Dunay A, Hadi A, Wibowo TS. Environmental economics and the SDGs: a review of their relationships and barriers. Sustainability. 2022;14(12):7513. https://doi.org/10.3390/SU14127513.
14. Govindan K, Shankar KM, Kannan D. Achieving sustainable development goals through identifying and analyzing barriers to industrial sharing economy: a framework development. Int J Prod Econ. 2020;227: 107575. https://doi.org/10.1016/J.IJPE.2019.107575.
15. Lawrence RJ. Overcoming barriers to implementing sustainable development goals. Human Ecology Matters. 2020. https://doi.org/10.3316/informit.741275513725761.
16. Allen C, Metternicht G, Wiedmann T. Initial progress in implementing the Sustainable Development Goals (SDGs): a review of evidence from countries. Sustain Sci. 2018;13(5):1453–67. https://doi.org/10.1007/S11625-018-0572-3/FIGURES/4.
17. Filho WL, et al. The economics of the UN Sustainable Development Goals: does sustainability make financial sense? Discov Sustain. 2022;3(1):1–8. https://doi.org/10.1007/S43621-022-00088-5/FIGURES/2.
18. Ögmundarson Ó, Herrgård MJ, Forster J, Hauschild MZ, Fantke P. Addressing environmental sustainability of biochemicals. Nat Sustain. 2020;3(3):167–74. https://doi.org/10.1038/s41893-019-0442-8.
19. Roy J et al. Sustainable development, poverty eradication and reducing inequalities. 2018. https://www.ipcc.ch/sr15/. Accessed 31 Oct 2023.
20. Gupta J, Vegelin C. Sustainable development goals and inclusive development. Int Environ Agreem. 2016;16(3):433–48. https://doi.org/10.1007/S10784-016-9323-Z/FIGURES/2.
21. Schmidt-Traub G, Kroll C, Teksoz K, Durand-Delacre D, Sachs JD. National baselines for the Sustainable Development Goals assessed in the SDG Index and Dashboards. Nature. 2017;10(8):547–55. https://doi.org/10.1038/ngeo2985.
22. Asma S, et al. Monitoring the health-related Sustainable Development Goals: lessons learned and recommendations for improved measurement. The Lancet. 2020;395(10219):240–6. https://doi.org/10.1016/S0140-6736(19)32523-1.
23. Annan-Diab F, Molinari C. Interdisciplinarity: practical approach to advancing education for sustainability and for the Sustainable Development Goals. Int J Manag Educ. 2017;15(2):73–83. https://doi.org/10.1016/J.IJME.2017.03.006.
24. Sweileh WM. Bibliometric analysis of scientific publications on 'sustainable development goals' with emphasis on 'good health and well-being' goal (2015–2019). Global Health. 2020;16(1):1–13. https://doi.org/10.1186/S12992-020-00602-2/FIGURES/5.
25. Olawumi TO, Chan DWM. A scientometric review of global research on sustainability and sustainable development. J Clean Prod. 2018;183:231–50. https://doi.org/10.1016/J.JCLEPRO.2018.02.162.
26. Pahrudin P, Liu LW, Li SY. What is the role of tourism management and marketing toward sustainable tourism? A bibliometric analysis approach. Sustainability. 2022;14(7):4226. https://doi.org/10.3390/SU14074226.
27. Raman R, Subramaniam N, Nair VK, Shivdas A, Achuthan K, Nedungadi P. Women Entrepreneurship and Sustainable Development: bibliometric analysis and emerging research trends. Sustainability. 2022;14(15):9160. https://doi.org/10.3390/SU14159160.
28. Khan A, Goodell JW, Hassan MK, Paltrinieri A. A bibliometric review of finance bibliometric papers. Financ Res Lett. 2022;47: 102520. https://doi.org/10.1016/J.FRL.2021.102520.
29. García EG, Magaña EC, Ariza AC. Quality education as a sustainable development goal in the context of 2030 Agenda: bibliometric approach. Sustainability. 2020;12(15):5884. https://doi.org/10.3390/SU12155884.
30. Sharifi A, Simangan D, Kaneko S. Three decades of research on climate change and peace: a bibliometrics analysis. Sustain Sci. 2021;16(4):1079–95. https://doi.org/10.1007/S11625-020-00853-3/TABLES/2.
31. Lotka AJ. The frequency distribution of scientific productivity. J Wash Acad Sci. 1926;16(12):317–23.
32. Bradford SC. Sources of information on specific subjects. Engineering. 1934;137:85–6. https://doi.org/10.18919/JKG.53.1_34.
33. Bernal JD. The social function of science. Routledge; 1939.
34. Zipf GK. Human behaviour and the principle of least-effort. Reading: Addison-Wesley; 1949. p. 24.
35. De Solla Price DJ. Networks of scientific papers. Science (1979). 1965;149(3683):510. https://doi.org/10.1126/SCIENCE.149.3683.510/ASSET/9FDF0602-F38E-4531-A077-709136377FFA/ASSETS/SCIENCE.149.3683.510.FP.PNG.
36. Merton RK. Priorities in scientific discovery: a chapter in the sociology of science. Am Sociol Rev. 1957;22(6):635. https://doi.org/10.2307/2089193.
37. Kessler MM. Bibliographic coupling between scientific papers. Am Doc. 1963;14(1):10–25. https://doi.org/10.1002/ASI.5090140103.
38. Garfield E. Science citation index'—a new dimension in indexing. Science (1979). 1964;144(3619):649–54. https://doi.org/10.1126/SCIENCE.144.3619.649/ASSET/90E1052A-BF90-4198-8CD2-4F2A3C55B9E5/ASSETS/SCIENCE.144.3619.649.FP.PNG.
39. Small H. Co-citation in the scientific literature: a new measure of the relationship between two documents. J Am Soc Inf Sci. 1973;24(4):265–9. https://doi.org/10.1002/ASI.4630240406.
40. Marshakova IV. Co-citation in scientific literature: a new measure of the relationship between publications. Sci Tech Inf Ser VINITI. 1973;6:3–8.

41. Pritchard A. Statistical bibliography or bibliometrics. J Document. 1969;25:348. https://doi.org/10.18919/JKG.53.1_34.
42. Nalimov VV, Mulchenko ZM, Naukometriya. English Translation: Scientometrics. Studying Science as an Information Process. US Air Force Systems Command, Foreign Technology Division, Washington DC, 1971, 1969.
43. Nacke O. Informetrie: Ein Neuer Name Fuer Eine Neue Disziplin. Begriffsbestimmung, Wissensstand Und Entwicklungsprinzipien. Nachr. Dokument.; DEU; DA, 1979; 30(6): 219–26.
44. van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics. 2009;84(2):523–38. https://doi.org/10.1007/S11192-009-0146-3.
45. Hirsch JE. An index to quantify an individual's scientific research output. Proc Natl Acad Sci. 2005;102(46):16569–72. https://doi.org/10.1073/PNAS.0507655102.
46. Egghe L. Theory and practise of the g-index. Scientometrics. 2006; 69(1): 131–152. https://doi.org/10.1007/s11192-006-0144-7
47. Tol RSJ. The h-index and its alternatives: an application to the 100 most prolific economists. Scientometrics. 2009;80(2):317–24. https://doi.org/10.1007/S11192-008-2079-7.
48. Lathabai HH. ψ-index: a new overall productivity index for actors of science and technology. J Informetr. 2020;14(4): 101096. https://doi.org/10.1016/J.JOI.2020.101096.
49. Lathabai HH, Nandy A, Singh VK. x-index: identifying core competency and thematic research strengths of institutions using an NLP and network based ranking framework. Scientometrics. 2021;126(12):9557–83. https://doi.org/10.1007/S11192-021-04188-3/TABLES/5.
50. Lathabai HH, Nandy A, Singh VK. Institutional collaboration recommendation: an expertise-based framework using NLP and network analysis. Expert Syst Appl. 2022;209: 118317. https://doi.org/10.1016/J.ESWA.2022.118317.
51. Paul J, Lim WM, O'Cass A, Hao AW, Bresciani S. Scientific procedures and rationales for systematic literature reviews (SPAR-4-SLR). Int J Consum Stud. 2021;45(4):O1–16. https://doi.org/10.1111/IJCS.12695.
52. Lim WM, Rasul T, Kumar S, Ala M. Past, present, and future of customer engagement. J Bus Res. 2022;140:439–58. https://doi.org/10.1016/J.JBUSRES.2021.11.014.
53. Donthu N, Kumar S, Pattnaik D. Forty-five years of Journal of Business Research: A bibliometric analysis. J Bus Res. 2020;109:1–14. https://doi.org/10.1016/J.JBUSRES.2019.10.039.
54. SciVal—Overview. https://www.scival.com/overview/summary?dgcid=ScopusHeader
55. RAWGraphs. https://www.rawgraphs.io/
56. SDG Toolkit. SDGs as a Network of Targets/Base View. Kumu. https://kumu.io/jeff/sdg-toolkit
57. Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ. The circular economy—a new sustainability paradigm? J Clean Prod. 2017;143:757–68. https://doi.org/10.1016/J.JCLEPRO.2016.12.048.
58. D'Amato D, et al. Green, circular, bio economy: a comparative analysis of sustainability avenues. J Clean Prod. 2017;168:716–34. https://doi.org/10.1016/J.JCLEPRO.2017.09.053.
59. Cheng M. Sharing economy: a review and agenda for future research. Int J Hosp Manag. 2016;57:60–70. https://doi.org/10.1016/J.IJHM.2016.06.003.
60. Chen L, Zhao X, Tang O, Price L, Zhang S, Zhu W. Supply chain collaboration for sustainability: a literature review and future research agenda. Int J Prod Econ. 2017;194:73–87. https://doi.org/10.1016/J.IJPE.2017.04.005.
61. Zyoud SH, Fuchs-Hanusch D. A bibliometric-based survey on AHP and TOPSIS techniques. Expert Syst Appl. 2017;78:158–81. https://doi.org/10.1016/J.ESWA.2017.02.016.
62. Hallinger P, Chatpinyakoop C. A bibliometric review of research on higher education for sustainable development, 1998–2018. Sustainability. 2019;11(8):2401. https://doi.org/10.3390/SU11082401.
63. Strifler L, et al. Scoping review identifies significant number of knowledge translation theories, models, and frameworks with limited use. J Clin Epidemiol. 2018;100:92–102. https://doi.org/10.1016/J.JCLINEPI.2018.04.008.
64. Kong L, Liu Z, Wu J. A systematic review of big data-based urban sustainability research: STate-of-the-science and future directions. J Clean Prod. 2020;273: 123142. https://doi.org/10.1016/J.JCLEPRO.2020.123142.
65. Kumar S, Sahoo S, Lim WM, Dana LP. Religion as a social shaping force in entrepreneurship and business: Insights from a technology-empowered systematic literature review. Technol Forecast Soc Change. 2022;175: 121393. https://doi.org/10.1016/J.TECHFORE.2021.121393.
66. Secinaro S, Brescia V, Lanzalonga F, Santoro G. Smart city reporting: a bibliometric and structured literature review analysis to identify technological opportunities and challenges for sustainable development. J Bus Res. 2022;149:296–313. https://doi.org/10.1016/J.JBUSRES.2022.05.032.
67. Moral-Muñoz JA, Herrera-Viedma E, Santisteban-Espejo A, Cobo MJ. Software tools for conducting bibliometric analysis in science: an up-to-date review. Profesional de la información. 2020;29(1):1699–2407. https://doi.org/10.3145/EPI.2020.ENE.03.
68. Persson O, Danell R, Schneider JW. How to use Bibexcel for various types of bibliometric analysis. Celebrating scholarly communication studies: a Festschrift for Olle Persson at his 60th Birthday; 2009.p. 9-24.
69. Bastian M, Heymann S, Jacomy M. Gephi: an open source software for exploring and manipulating networks. In: In Proceedings of the international AAAI conference on web and social media; 2009. p. 361–2.
70. Cobo MJ, Lõpez-Herrera AG, Herrera-Viedma E, Herrera F. SciMAT: a new science mapping analysis software tool. J Am Soc Inform Sci Technol. 2012;63(8):1609–30. https://doi.org/10.1002/ASI.22688.
71. Chen C. CiteSpace: a practical guide for mapping scientific literature book: representing scientific knowledge: the role of uncertainty view project book: turning points: the nature of creativity. Springer; 2011.
72. Aria M, Cuccurullo C. bibliometrix: an R-tool for comprehensive science mapping analysis. J Informetr. 2017;11(4):959–75. https://doi.org/10.1016/J.JOI.2017.08.007.
73. Rashidi K, Noorizadeh A, Kannan D, Cullinane K. Applying the triple bottom line in sustainable supplier selection: a meta-review of the state-of-the-art. J Clean Prod. 2020;269: 122001. https://doi.org/10.1016/J.JCLEPRO.2020.122001.
74. Mura M, Longo M, Micheli P, Bolzani D. The evolution of sustainability measurement research. Int J Manag Rev. 2018;20(3):661–95. https://doi.org/10.1111/IJMR.12179.

75. Feng Y, Zhu Q, Lai KH. Corporate social responsibility for supply chain management: a literature review and bibliometric analysis. J Clean Prod. 2017;158:296–307. https://doi.org/10.1016/J.JCLEPRO.2017.05.018.
76. Dhamija P, Bag S. Role of artificial intelligence in operations environment: a review and bibliometric analysis. TQM J. 2020;32(4):869–96. https://doi.org/10.1108/TQM-10-2019-0243/FULL/PDF.
77. Duque-Acevedo M, Belmonte-Ureña LJ, Cortés-García FJ, Camacho-Ferre F. Agricultural waste: review of the evolution, approaches and perspectives on alternative uses. Glob Ecol Conserv. 2020;22: e00902. https://doi.org/10.1016/J.GECCO.2020.E00902.
78. Abad-Segura E, González-Zamar MD, Infante-Moro JC, García GR. Sustainable management of digital transformation in higher education: global research trends. Sustainability. 2020;12(5):2107. https://doi.org/10.3390/SU12052107.
79. Abduljabbar RL, Liyanage S, Dia H. The role of micro-mobility in shaping sustainable cities: a systematic literature review. Transp Res D Transp Environ. 2021;92: 102734. https://doi.org/10.1016/J.TRD.2021.102734.
80. Furstenau LB, et al. Link between sustainability and industry 4.0: trends, challenges and new perspectives. IEEE Access. 2020;8:140079–96. https://doi.org/10.1109/ACCESS.2020.3012812.
81. Agusdinata DB, Liu W, Eakin H, Romero H. Socio-environmental impacts of lithium mineral extraction: towards a research agenda. Environ Res Lett. 2018;13(12): 123001. https://doi.org/10.1088/1748-9326/AAE9B1.
82. Dos Santos PH, Neves SM, Sant'Anna DO, de Oliveira CH, Carvalho HD. The analytic hierarchy process supporting decision making for sustainable development: an overview of applications. J Clean Prod. 2019;212:119–38. https://doi.org/10.1016/J.JCLEPRO.2018.11.270.
83. Li X, Wu P, Shen GQ, Wang X, Teng Y. Mapping the knowledge domains of Building Information Modeling (BIM): a bibliometric approach. Autom Constr. 2017;84:195–206. https://doi.org/10.1016/J.AUTCON.2017.09.011.
84. Di Vaio A, Palladino R, Hassan R, Escobar O. Artificial intelligence and business models in the sustainable development goals perspective: a systematic literature review. J Bus Res. 2020;121:283–314. https://doi.org/10.1016/J.JBUSRES.2020.08.019.
85. Schöggl JP, Stumpf L, Baumgartner RJ. The narrative of sustainability and circular economy—a longitudinal review of two decades of research. Resour Conserv Recycl. 2020;163: 105073. https://doi.org/10.1016/J.RESCONREC.2020.105073.
86. Sharma R, Jabbour CJC, Lopes de Sousa Jabbour AB. Sustainable manufacturing and industry 4.0: what we know and what we don't. J Enterprise Inf Manag. 2020;34(1):230–66. https://doi.org/10.1108/JEIM-01-2020-0024/FULL/PDF.
87. Pizzi S, Caputo A, Corvino A, Venturelli A. Management research and the UN sustainable development goals (SDGs): a bibliometric investigation and systematic review. J Clean Prod. 2020;276: 124033. https://doi.org/10.1016/J.JCLEPRO.2020.124033.
88. Bartolacci F, Caputo A, Soverchia M. Sustainability and financial performance of small and medium sized enterprises: a bibliometric and systematic literature review. Bus Strategy Environ. 2020;29(3):1297–309. https://doi.org/10.1002/BSE.2434.
89. Zhang X, Li H. Urban resilience and urban sustainability: what we know and what do not know? Cities. 2018;72:141–8. https://doi.org/10.1016/J.CITIES.2017.08.009.
90. Si H, Gang Shi J, Wu G, Chen J, Zhao X. Mapping the bike sharing research published from 2010 to 2018: a scientometric review. J Clean Prod. 2019;213:415–27. https://doi.org/10.1016/J.JCLEPRO.2018.12.157.
91. Zhu J, Hua W. Visualizing the knowledge domain of sustainable development research between 1987 and 2015: a bibliometric analysis. Scientometrics. 2017;110(2):893–914. https://doi.org/10.1007/S11192-016-2187-8/FIGURES/9.
92. Garrigos-Simon FJ, Narangajavana-Kaosiri Y, Lengua-Lengua I. Tourism and sustainability: a bibliometric and visualization analysis. Sustainability. 2018;10(6):197. https://doi.org/10.3390/SU10061976.
93. Sharifi A, Khavarian-Garmsir AR. The COVID-19 pandemic: impacts on cities and major lessons for urban planning, design, and management. Sci Total Environ. 2020;749: 142391. https://doi.org/10.1016/J.SCITOTENV.2020.142391.
94. Gusmão Caiado RG, Leal Filho W, Quelhas OLG, Luiz de Mattos Nascimento D, Ávila LV. A literature-based review on potentials and constraints in the implementation of the sustainable development goals. J Clean Prod. 2018;198:1276–88. https://doi.org/10.1016/J.JCLEPRO.2018.07.102.
95. Martins VWB, Rampasso IS, Anholon R, Quelhas OLG, Leal Filho W. Knowledge management in the context of sustainability: literature review and opportunities for future research. J Clean Prod. 2019;229:489–500. https://doi.org/10.1016/J.JCLEPRO.2019.04.354.
96. Leal Filho W, et al. The role of transformation in learning and education for sustainability. J Clean Prod. 2018;199:286–95. https://doi.org/10.1016/J.JCLEPRO.2018.07.017.
97. Hallinger P. Bringing context out of the shadows of leadership. Educ Manag Admin Leadership. 2018;46(1):5–24. https://doi.org/10.1177/1741143216670652/ASSET/IMAGES/LARGE/10.1177_1741143216670652-FIG2.JPEG.
98. Aznar-Sánchez JA, Piquer-Rodríguez M, Velasco-Muñoz JF, Manzano-Agugliaro F. Worldwide research trends on sustainable land use in agriculture. Land Use Policy. 2019;87: 104069. https://doi.org/10.1016/J.LANDUSEPOL.2019.104069.
99. Nascimento DLM, et al. Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: a business model proposal. J Manuf Technol Manag. 2019;30(3):607–27. https://doi.org/10.1108/JMTM-03-2018-0071/FULL/PDF.
100. Vega-Muñoz A, Arjona-Fuentes JM, Ariza-Montes A, Han H, Law R. In search of 'a research front' in cruise tourism studies. Int J Hosp Manag. 2020;85: 102353. https://doi.org/10.1016/J.IJHM.2019.102353.
101. Huang J, Gates AJ, Sinatra R, Barabási AL. Historical comparison of gender inequality in scientific careers across countries and disciplines. Proc Natl Acad Sci U S A. 2020;117(9):4609–16. https://doi.org/10.1073/PNAS.1914221117/SUPPL_FILE/PNAS.1914221117.SAPP.PDF.
102. Li J, Wang J. Comprehensive utilization and environmental risks of coal gangue: a review. J Clean Prod. 2019;239: 117946. https://doi.org/10.1016/J.JCLEPRO.2019.117946.
103. Martens ML, Carvalho MM. Key factors of sustainability in project management context: a survey exploring the project managers' perspective. Int J Project Manage. 2017;35(6):1084–102. https://doi.org/10.1016/J.IJPROMAN.2016.04.004.
104. SDG Mapper Intro | KnowSDGs. https://knowsdgs.jrc.ec.europa.eu/sdgmapper
105. Allison EH, et al. Policy: map the interactions between Sustainable Development Goals. Nature. 2016;534(7607):320–2. https://doi.org/10.1038/534320a.
106. Le Blanc D. Towards integration at last? The Sustainable Development Goals as a network of targets. Sustain Dev. 2015;23(3):176–87. https://doi.org/10.1002/SD.1582.
107. Sreenivasan A, Suresh M, Nedungadi P, Raghu Raman R. Mapping analytical hierarchy process research to sustainable development goals: bibliometric and social network analysis. Heliyon. 2023;9(8):e19077. https://doi.org/10.1016/J.HELIYON.2023.E19077.

108. Raman R, Lathabhai H, Mandal S, Kumar C, Nedungadi P. Contribution of business research to Sustainable Development Goals: bibliometrics and science mapping analysis. Sustainability. 2023;15(17):12982. https://doi.org/10.3390/SU151712982.
109. Carter CR, Ellram LM, Tate W. The use of social network analysis in logistics research. J Bus Logist. 2007;28(1):137–68. https://doi.org/10.1002/J.2158-1592.2007.TB00235.X.
110. Hansen PR, Lunde A, Nason JM. The model confidence set. Econometrica. 2011;79(2):453–97. https://doi.org/10.3982/ECTA5771.
111. Raman R, et al. Mapping sustainability reporting research with the UN's sustainable development goal. Heliyon. 2023;9(8): e18510. https://doi.org/10.1016/J.HELIYON.2023.E18510.
112. Rodrigues M, Mendes L. Mapping of the literature on social responsibility in the mining industry: a systematic literature review. J Clean Prod. 2018;181:88–101. https://doi.org/10.1016/J.JCLEPRO.2018.01.163.
113. Ye N, Kueh TB, Hou L, Liu Y, Yu H. A bibliometric analysis of corporate social responsibility in sustainable development. J Clean Prod. 2020;272: 122679. https://doi.org/10.1016/J.JCLEPRO.2020.122679.
114. Sarkar S, Searcy C. Zeitgeist or chameleon? A quantitative analysis of CSR definitions. J Clean Prod. 2016;135:1423–35. https://doi.org/10.1016/J.JCLEPRO.2016.06.157.
115. Abad-Segura E, Cortés-García FJ, Belmonte-Ureña LJ. The sustainable approach to corporate social responsibility: a global analysis and future trends. Sustainability. 2019;11(19):5382. https://doi.org/10.3390/SU11195382.
116. Grosseck G, Tîru LG, Bran RA. Education for sustainable development: evolution and perspectives: a bibliometric review of research, 1992–2018. Sustainability. 2019;11(21):6136. https://doi.org/10.3390/SU11216136.
117. Avelar ABA, de Silva-Oliveira KD, de Pereira RS. Education for advancing the implementation of the Sustainable Development Goals: a systematic approach. Int J Manag Educ. 2019;17(3):100322. https://doi.org/10.1016/J.IJME.2019.100322.

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# How digitalization saved 2020 European Capitals of Culture



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## Abstract

**Purpose** – The objective of this work is to identify the strategies of digitalization embraced by the European Capitals of Culture 2020 (ECoC) in replying to the limitations due to COVID-19 emergence and to understand how DT have impacted in terms of resilience and innovation. This study aims to provide a contribution at the understanding of the effects and benefits of the digitalization in supporting the reorganization of the cultural projects of ECoC 2020 in replying to the COVID-19.

**Design/methodology/approach** – This paper is based on an exploratory multiple case study methodology. As a suitable investigative tool for the analysis of a contemporary phenomenon in their natural settings, case study methodology allows to integrate evidences resulting from multiple sources (Yin, 2006, 2008; Eisenhardt, 1989). Data collection, monitoring and analysis rely on the combination of Web-based desk analysis and social big data analytics. The integration of such sources has been addressed towards the investigation of the strategies of digitalization undertaken by the two ECoC cities, Galway in Ireland and Rijeka in Croatia, respectively.

**Findings** – Evidences in terms re-organization of the cultural projects, digitalization of the tourist experiences, commitment of local communities and visitors have been derived from the study while the cross comparison of the two cases has allowed to identify common and specific patterns.

**Research limitations/implications** – The paper presents some limitations. Firstly, the methodological approach as well as the nature of data collected suggest the need of future investigation with the inclusion of a larger sample of ECoCs and the inclusions of quantitative date related to trends of online cultural experiences and travel data. Secondly, the theoretical perspective of digitalization used in this study can be accompanied by other perspectives such as innovation and resilience capabilities of an ECoC.

**Originality/value** – This study contributes to the academic literature by providing a better understanding of the level of resilience generated vis-à-vis the COVID-19 pandemic and the role of DT in promoting participation in culture and implementing cultural initiatives of ECoCs. However, despite the relevance of the topic, the attention from the academic literature on the topic of digitalization in cultural and creative industries is still limited. Moreover, even more limited is the knowledge about the effects of DT and if their opportunities are actually transformed in positive outcomes.

**Keywords** Digitalization, Digital participation, Capital of culture, Knowledge sharing, Resilience

**Paper type** Case study

## 1. Introduction

Given the disruptive character of digital transformation in the latest years, which has created a hyper-connected culture, all types of business are changing their atmosphere, organizations, values, processes, models and services. This circumstance has been exacerbated by COVID-19 pandemic that, bringing in a high level of uncertainty related to the contagion emergency (Altig *et al.*, 2020; Govindan *et al.*, 2020), has forced all organizations to reinvent their business strategies (Seetharaman, 2020). The pervasiveness of DT in all areas of human activity poses a major challenge to organizational thinking: to be able to interpret the great changes taking place, recognising that the two areas of technological choices and organizational choices are not mutually exclusive (Garzoni *et al.*, 2020).

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It is also true that digital transformation is not something new, it already existed before pandemic to the extent that organizations used advanced DT for conducting online trading, analysis, surveillance and server less computing (Brigo *et al.*, 2020; Lee and Trimi, 2020). However, such exceptional contagious crisis has impacted also on cultural institutions that are constantly changing as well as their management systems, methods of artefacts preservation and conservation, offers to customers and users, management skills. This continuous changing can be interpreted not only as positive but also as a necessary element, which helps creating and maintaining a strong tie with citizens and society. The way people interact with cultural offers and products is also constantly changing. The digital tool is seen as fundamental in such a relationship especially during the pandemic period that has intensified the use of digital as a tool for virtual experiences declined in different ways. During the pandemic, digitalization has been the driving force in all professional sectors, as well as in personal lives (Jayawardana *et al.*, 2022) but it has been crucial for the realm of culture, hospitality and tourism business (Valeri, 2022; Deb *et al.*, 2022; Zheng *et al.*, 2022).

Cultural containers as well as events have questioned themselves as well as the habits of a public who moves around very quickly by seeking to establish an empathic relationship with the public itself. In a contemporary scenario, in which DT is the tool that enables that the relationship between institutions and users is nurtured and sustained, the participatory aspect is fundamental (Buhalis, 2019; Del Baldo and Demartini, 2021). Such participation starts 'from the bottom' and its kernel of the truth is made by individuals' unique experiences.

This is the dimension that cultural institutions have to deal with as providing access to content only is not enough; rather, what become pivotal is to involve and give voice to people. By this light, digital tools and methods of citizens' engagement is crucially important: it is the citizens who interpret, connect and narrate texts, images, objects.

Citizen engagement can also be activated by crowdsourcing projects, which are becoming increasingly popular such as participatory platforms and where projects are created directly by interactive citizens as well as institutions. DT plays a decisive role in ensuring accessibility and inclusion. They must be part of a holistic process of digital transformation; the choice of a technology is not enough, but it must be accompanied by a well-defined strategy (Buhalis, 2019). It must be part of the process defined as digital transformation, which is not to be understood only as a technological change, but as a real cultural process. Cultural industry cannot escape such a revolution, as it must learn to manage it appropriately and effectively, with a methodology suited to the current situation, without giving pace to ill-suited tools (Bakhshi and Throsby, 2012). Therefore, it is a matter of developing a new way of thinking about the role of DT as a means of improving the experience of people, both visitors and professionals, management systems and the conservation and care of heritage especially at the aftermath of the COVID-19 pandemic outbreak and its disasters (Korkmaz and Toraman, 2020). In this perspective, the debate on the effects of COVID-19 on larger cultural and creative industries results to be populated by cross-disciplinary contributions focused on the different disruptive effects in terms of digital transformation of cultural organizations, virtualization of cultural events and experiences, and new business models for cultural organizations (Massi *et al.*, 2020).

However, DT are recognized as sources producing positive outcomes in the cultural industry and their benefits are expected to continue also after the pandemic emergence since they are currently assumed as tools enabling self-fulfilment and self-expression for individuals (Corvello *et al.*, 2022). In the fluorescent debate associated to the digitalization of cultural industry during and after the pandemic emergence there is a dimension which has been marginally considered. The latter refers to the effects on cultural events with collective dimensions such as the European Capitals of Culture (ECoCs). Accordingly, this paper aims to understand how DT have impacted on cultural projects of ECoCs 2020 and to explore their effects on communities in terms of resilience and innovation.

This paper is based on the contributions of both theory digitalization and resilience. The concept of digitalization applied to the cultural industry is briefly discussed by referring to the latest technological advancement, more specifically, in the realm of social digital solutions. The novelty of this work relates to the acknowledgement of how digitalization enables organizational agility to transform due to a global crisis and to develop resilient aptitude in the era of digital transformation. The remaining of the paper is structured as follows: in the next section, the literature background is presented with a focus on the digital transformation in the cultural industry and its resilience in COVID-19 emergence. The methodology presents the multiple case study as a qualitative approach adopted for the empirical investigation and the main phases. Findings synthetize the results related to the two ECoCs 2020 in terms of cultural projects, lockdown limitations and strategies implemented, and the role of DT in supporting the achievement of the cultural goals of ECoCs' programmes. In the conclusions, the main implications for theory and practice are recalled with the study limitations and areas for future research.

## 2. Literature review

### *2.1 Digital transformation in the cultural industry*

If one considers that the word 'digital' applies to the organizational, the strategic, and the innovation realms, digital transformation is seen as a pervasive innovation that integrates into all extents of sectors and activities so to generate ultimate transformation in the way organizations work and provide value to consumers/end users (Kagermann, 2015). Moreover, it is important to argue that digital transformation stands as a social change for organizations involved in such an innovation revolution that are dramatically concerned with the issue of survival. As it has been put forward, digital transformation represents an *'evolutionary process that leverages digital capabilities and technologies to create unique value for business models, operational procedures, and customer experiences'* (Jayawardana *et al.*, 2022, p. 1). This is true, more than ever, after the outbreak of the COVID-19 pandemic when organizations have struggled to continue to guarantee supply chain values while adapting to the newly established scenario (Purcell and Charles, 2020).

Given pervasiveness of digital transformation in people's life (Demir, 2019; Guryanova *et al.*, 2020), existing technological advancement have consequently led to improvement of the values of life (Sun *et al.*, 2020). Smart technology, at the foremost, contributes to simplify the activities carried out by customers and business thanks to interoperability and interconnection of users and business that exchange whatever data in dynamic platforms (Leung, 2019). In the cultural industry, technology based development has walked in tandem with changes occurred in the sector by the advent of ICT. Progress in this sector has allowed cultural destinations and sites to become more attractive so that they have turned into places of value co-creation and information sharing (Akehurst, 2009; Porter and Heppelmann, 2014). By this light, it can be argued that cultural products and artefacts are, no longer, the result of an institutional effort of storytelling and narration but the experience of individual customers entrenched with his/her personal cultural and social background (Zhong *et al.*, 2017). ICT, in fact, make use of a comprehensive approach aiming to enhance quality of life by supporting integration and participation of the community (Dredge *et al.*, 2018). As argued, diverse types of integration with digital community exist and refer, amongst those, to digital citizenship and social inclusion (McLoughlin and Lee, 2010; Noh and Tolbert, 2019). This allows cultural industry, in this specific context, to leverage on the collective intelligence of customers to generate advantages, hence, an enhanced cultural value (Allam and Newman, 2018; Harrison *et al.*, 2010).

In order to take advantage from the chances provided by digital transformation, technological solutions in the cultural industry become able to support evidence-based decision-making (Bakhshi and Throsby, 2012) that is essential for the development of a different type of cultural offering with positive effects on customers, as individuals and on the community, as a whole (Femenia-Serra and Ivars-Baidal, 2018). There are several solutions such as geo-referenced data, cloud computing combined with smart phones, end-user services (Volo, 2019), which help delivering more personalized cultural experiences while guaranteeing a transition towards a more competitive, yet smart cultural offering (Femenia-Serra, 2018; Wang *et al.*, 2016). Such digital solutions, hence, represent the main driver for improving organizational capabilities in the cultural industry to the extent that they contribute to define experiences through innovative technology and enhance users' engagement while increasing the personalization of cultural offering.

Moreover, as the quantitative study conducted in China by Zheng *et al.* (2022) has demonstrated that the use of smart technology gives a significant contribution to effective planning in tourism destinations. This research adds value to innovation studies in tourism to the extent that it demonstrates the significant role played by smart technology in affecting tourist satisfaction that, at turn, has also an impact on tourists' intention to revisit places. In the attempt to connect respondents' smart technology usage to their attitudes towards various cultural services during their visit in the destination, this study also contributes to shed more light on the emerging concepts such as smart tourism and smart tourist destinations.

Amongst the digital solutions used which trigger users' engagement and involvement are Big Social Data (Schroeder, 2014). They derive from user-generated content through popular social online services, such as Instagram, Twitter, YouTube, Facebook but also online blogs (Burgess and Bruns, 2012). Research has given evidence that social media, because are increasingly being used in everyday lives so to produce significant transformations, do create an extensive quantity of data to be used for research purposes (Shaikh *et al.*, 2017). By this perspective, massive amounts of data (whether unstructured or organized) that is built through social media networks stands as the origin of big data which is referred as Big Social Data. The kernel of the truth about big social data is that, as argued, they become significant to analyse as they enable to take better decision (Grover and Kar, 2017).

Nevertheless, different interpretations are found in the existing literature on this topic as they refer to how the term 'social' is used in connection to Big Data. Eminent scholars in this field as Flesch *et al.* (2015), Vatrapu *et al.* (2016) have emphasized more on the shift that Big Data had on the front of communication, media, computational and cultural social science. In this perspective, the authors have stressed the role of social media in the realm of contemporary media by identifying ethical issues together with the concern of data accessibility, reliability and authenticity.

To continue, other scholars have emphasized on the interrelation occurring between social data and physical data for the sake of the benefit of the audience (Ducange *et al.*, 2018); while others, such as Hennig *et al.* (2016) have concentrated on Big Social Data that enable to extract perceptions from people's online social interactions and social media data to impact on human decision-making. As argued, because people are enabled to share views, ideas and opinions in a transparent and loud manner, Big Social Data are given the chance to become handy tools that help improving data-driven decision-making process (Rahman and Reza, 2022). By this light, cultural offerings are the result of a co-creation process leading to personalized products/services, which promotes not merely networking but, above all, innovation and collaboration (Del Vecchio *et al.*, 2018). Such an active participation by means of social web platforms also triggers a process of online cultural experience of co-design that increases the value for end-users and, at the same time, generates higher satisfaction for them (Petit *et al.*, 2019). As argued, the value of co-creation through the cultural experience design is, thus, reinforced in as much as the concept of co-design that, at turn, strengthen the service-dominant logic (Del Baldo and Demartini, 2021). The latter, in fact, means that end users/customers become co-designers and are engaged in the process of co-design and co-creation driven innovation (Svensson and Grönroos, 2008; Park *et al.*, 2015). By this light, it can be argued that value is created for the cultural industry and for its users *'in every aspect of the value chain and that it is the beneficiary who always uniquely and phenomenologically determines this value through value in use perceptions'* (Merz *et al.*, 2018, p. 79). This assumption leads to the conclusion that digital solutions, which make use of web social platforms, applied to the cultural industry not only enhance a cultural experience of co-design but also underpins the overall value for both cultural decision makers and end-users.

Along these lines, there is a recently relevant study published by Deb *et al.* (2022) that has focused on the strategic role of digital marketing solutions in the sector of tourism business. The relevance of this study lies in the fact that it was conducted just after the COVID-19 pandemic, hence, during the new normal era as the authors call it, in order to measure both the intentionality of using digital marketing strategies and the level of digital renovation at the level digital renovation applications in the realm of tourism business. Results of this study show that because digital solutions (i.e. social media marketing) are perceived as useful and comfortable to use, they concur to enhance performance at the level of tourism business. Therefore, this research demonstrate that the adoption of digital practices triggers tourism providers and users' engagement and involvement to the extent that an authentic relationship between the use of digital practices and tourists' satisfaction is generated.

### *2.2 Resilience of the cultural industry after COVID-19*

As considered, digital transformation has helped organizations to increase productivity and reduce costs but, most importantly, to foster the dynamic capabilities for sustainability in a time of urgency. Digital transformation has leveraged on speed and compliance as important elements of controlling the disastrous circumstances brought in by the early 2020 COVID-19 pandemic's outbreak. The current context after COVID-19, has required urgent and necessary attention to the values underlying the use of technology, and has stimulated a different and much deeper perspective on the relationship between resilience and technology. The aforementioned study by Deb *et al.* (2022) is the first one conducted just after the pandemic that has attempted to explore the relationship between tourism business performance and digital marketing. This study, it can be argued, represent a resilient effort for the sake of local community's empowerment and tourism business expansion. On these lines, another relevant study conducted in Sri Lanka by Jayawardana *et al.* (2022), has given a significant contribution to increasing theoretical knowledge in technology acceptance by providing evidence on elements and factors facilitating success and effectiveness of digital transformation in a country that need to face a technology-rich global competition.

As argued, resilience is the ability to cope with difficulties in a positive way, giving new impetus to people's life. The diffusion of the concept of resilience in the international community has paved the way for many different interpretations of the term (Adger, 2000, 2003) initiating a process of cultural hybridization that has made resilience a boundary domain, closely linked to the dynamic nature of the processes that bind together the physical, social and economic dimensions of contemporary society (Brand and Jax, 2007).

Beyond the definitional problems that enable the usage of the concept across all scientific fields (Bennett *et al.*, 2005), there is one certainty about the concept itself so that it is placed in new epistemology of complexity: resilience is systemic. Resilience essentially refers to behaviours and processes that involve multifactorial interaction between phenomena and/or systems (Allen *et al.*, 2005). It involves the management of information according to process models, capable of prefiguring alternative scenarios of knowledge and operability through which to measure and assess the nature and quantity of the transformations themselves (Batabyal, 1998).

Nevertheless, the resilience approach implies the adoption of an open, complex and flexible outlook (Giovannini *et al.*, 2020) that is oriented towards new behaviour from all actors involved for the efficiency of organizations under stressful conditions (Olsson *et al.*, 2004).

It would be important to read resilience according to two perspectives: transformative and operational.

Transformative resilience actions include the promotion of economic behaviour geared towards collective well-being (Folke, 2006). The preservation and strengthening of the cultural infrastructure occurs by fostering an integrated relationship between the spheres of culture, education and tourism. The practice of resilience is oriented towards (a) investing in transversal skills as a vector of change; (b) fostering social inclusion and active participation for the common good; (c) sharing practices for the development of the territory; (d) proposing new well-being policies.

Operational resilience, instead, is understood as the ability to respond to the following question: *'resilient of what, to what'* (Carpenter *et al.*, 2001) and can be traced back to the definition of resilience as *'the ability of the system to maintain its identity in the face of internal change and external shocks and disturbances'* (Cumming *et al.*, 2005).

Thus, operational resilience is requested to meet a new set of hazardous specific and site-specific needs. This is done to orient interventions towards adaptation and/or mitigation strategies that are functional to both reduce the vulnerability of the observed context and the hazard of expected phenomena.

The operational side of resilience refers to definition of strategies and tools to operate in pro-active terms by managing the risk and vulnerability. In this sense, the application of operational resilience, accompanied by its transformative impetus, to the cultural industry has stressed the role of technology that has represented a means for managing complex processes for decision-making and design.

By this perspective, resilience has enabled the design of practices aimed at developing conditions of innovation (of product and process) through which to intervene for the mitigation of impacts according to the new paradigm of innovation.

The question of resilience with technology is not only a human but also a humanist resilience (Gunderson and Pritchard, 2002). On top of it there is technology, a tool of transformative resilience thanks to which one can/should imagine a connection between individual freedom needs and community instances. Again, technology is viewed as a tool that will make it possible to address the issue of scarcity of resources and inequalities.

As argued, human relationality and sociality have shown that they can enjoy forms of resilience thanks to the digitization of connections and a certain digital surrogacy of interpersonal and social relations (Janssen *et al.*, 2006). The technological resilience which appeared powerfully during the COVID-19 crisis carries within it certain trends of social transformation. And this is very much in the cultural and creative sector where resilience has taken a cultural dimension. Although constraints on cultural freedom imposed by restrictive COVID-19 measures, cultural resilience has allowed adaptation to risk and change by all those professionals and people involved in the sector by guaranteeing continuity of their artistic activities and exchanges of practices through online performance (Thiele, 2016; Holtorf, 2018). What has happened during the pandemic also given us indications of possible future transformations of our societies. It is crucial that, even in the context of relocalized productive activities, special attention has been paid to strengthening community dimensions on the territory as a social alternative to centralized places that, as argued, have characterized the past (Olsson *et al.*, 2006).

The following table provides a comprehensive list of the main bibliographic references included in the background and the respective research gap areas.

### 3. Methodology

The paper adopts a multiple case study methodology as a suitable investigative approach for the analysis of contemporary phenomena in their natural setting (Yin, 1994, 2003). The case study allows integrating data from various types of multiple sources by enabling to achieve a larger comprehension of the case (Eisenhardt, 1989) and this is preferable when the boundaries between the phenomenon and the context are not clear (Glaser and Strauss, 1967; Miles and Huberman, 1984). Consistently with the qualitative research approach described by Strauss and Corbin (1990) and Yin (1994, 2003), a case study methodology supports the understanding of phenomena through the observation of variables and their interacting relationships and it is useful when the separation of the object of the observation from its context is more critical. Furthermore, it is proved to be useful when the observation of social phenomena requires the interpretation by researchers. According to Massi *et al.* (2020), case study methodology offers interesting evidences for the advancement of the knowledge about digital transformation occurring into the domain of cultural and creative industries.

Empirical evidences have been collected through the integration of web-based secondary data and social media big data analytics resulting from the consultation of official accounts of both ECoCs on the main social networks. About secondary data, the investigation has been addressed towards the identification of official reports, press review, and mainly online interviews to strategic actors involved into the organization and management of cultural projects. In coherence with the consolidated practice of data collection from web sources (Barrett and Twycross, 2018; Rabianski, 2003), the usage of such data is recognized as a useful basis of evidence (Gunawan *et al.*, 2022). As for social networks, data collection referred to the monitoring and transcription of data associated to the main KPIs in terms of users' commitment and communicational performances (Peng *et al.*, 2016).

In developing the cases, the analysis referred to the typical phases of the methodological approach theorized by Yin (1994, 2003) by following the key phases synthetized in Figure 1.

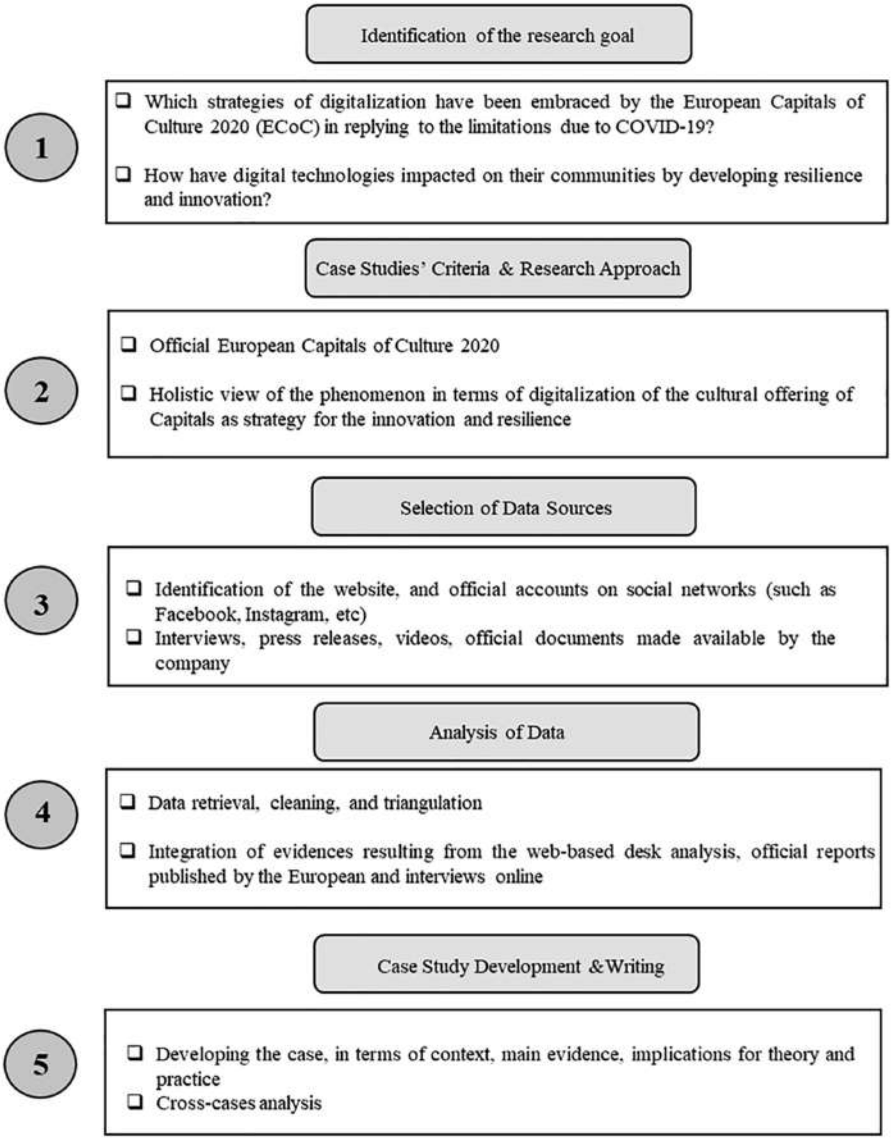
In Phase 1 related to the identification of the research goal, the research question has been developed starting from the research gap identified into the literature. This was possible by focusing on the need of exploring how digitalization supported ECoC in replying to the limitations due to Covid-19 and how DT impacted in terms of resilience and innovation.

About the Phase 2, criteria for the case studies' selection have been defined for the scouting of empirical phenomena relevant for the research goal and coherently with the ECoC that have experimented the lockdown limitations in the development of their annual projects and for which there could be identified consolidated evidences into a defined temporal horizon. In coherence with the theoretical background, the investigative approach has to be characterized by a holistic approach supporting the exploration of dynamics of innovation and resilience.

Sources of data have been defined into Phase 3 with the purpose of identifying a large and meaningful sample of digital tools and secondary sources including official web-sites and accounts on the main social media platforms, interviews, press releases, and official documents.

Phase 4 focused on Data Analysis with a procedural framework that has included activities of data retrieval. This has been possible also through collection and categorization of different typologies of data subjected to a first screening, conducted autonomously by the researchers, and consequent jointly validation, and to triangulation of data from the different sources to assure the correct interpretation of evidence provided.

In phase 5, collected data have been elaborated and clustered according to thematic areas. This has enabled a deeper understanding of both the two cases in terms of research context, ECoCs' cultural projects, cultural project limitations and new strategies implemented, and, the last but not the least, the role of DT in supporting the achievement of the cultural goals of ECoCs programs. A final step has regarded a cross-cases analysis.




**Source(s):** Author's own creation

**Figure 1.**
A five phases' analysis of the methodological approach

*3.1 Research context*

The research focuses on the experience of the two European Capitals of Culture 2020: Rijeka in Croatia and Galway in Ireland. As far as the city of Rijeka is concerned, it is the second Croatian city to be awarded the title of European Capital of Culture. Characterized by a very turbulent and articulated history, Rijeka is a border town, always disputed for different reasons. Firstly, by virtue of its strategic position along the Adriatic coast, in the Kvarner

Gulf; secondly, because of presence of an important shipyard which has shaped its recent history. It was a free port, thus, an autonomous entity of the crown of the Kingdom of Hungary from the end of the eighteenth century to the beginning of the twentieth century, within the Austrian Empire first and the Austro-Hungarian, later. From 1920 to 1924, it constituted the Free State of Rijeka (known as Fiume, in Italy) before being annexed to the Kingdom of Italy until '45. Later, it passed to Yugoslavia but in 1991, after its dissolution, it passed under the Croatian jurisdiction so to definitively take the name of Rijeka (which in Croatian means, in fact, 'river'). The main legacy of the many historical disputes that have affected the city is identifiable in various aspects. Firstly, the melting pot of populations that determine its current ethnic composition (for the most part Croats, Serbs, Bosnians, Italians and Slovenes). Secondly, in the extraordinary and articulated cultural vivacity of this small city that bears the signs of a past that is not always easy, but that was able to turn them into strengths. It is thanks to the enhancement of such distinctive features that Rijeka has presented itself to Europe as the European Capital for Culture 2020 by using the motto 'Port of Diversity'.

Galway, instead, is a city of about 80,000 inhabitants located in the north-west of Ireland. It stands as the third Irish city in line to have won the title of European Capital of Culture relatively for the year 2020. The origins of the city of Galway seem to date back to the early twelfth century with the construction of a fortress in 1,124 along the banks of the River Corrib by the then King of the Irish Region of Connacht, of which it is still part today. At the beginning of the thirteenth century, the castle was conquered by Richard Mor de Burgh, King of the Anglo-Normans whose descendants ruled the city for over a hundred years. After the fall of the de Burgh family, Galway gained independence from the British Crown in 1,484. During the 1,600, it was a protagonist in the Gaelic rebellions to fight against the English domination on the island by participating in two wars whose outcome was, however, unfavourable to the Irish-independence cause. From that moment on, the city began a centuries-old decline that did not end until the economic boom of the late twentieth century. Today, it shows itself as a city in rapid economic and demographic growth, with a very young population compared to Irish standards, mainly due to the presence of an important university, the National University of Ireland of Galway.

## 4. Findings

The analysis of the two cases has been addressed towards the identification of projects approved with their election at European Capital of Culture, the strategy implemented for overcoming the limitations due to COVID-19, the role of DT in supporting the achievement of the cultural goals of their programmes.

### *4.1 Cultural projects*

The cultural project at the basis of the election of Rijeka as European Capital of Culture can be synthetized into the slogan that has marked the whole event that is 'Port of Diversity'. The latter connects the cultural program with the model of multiculturalism and tolerance that distinguish inhabitants and the administrative policies of Rijeka. The themes that -characterize the entire cultural experience are basically three: water, work, migration.

As distinctive element characterizing the city because of its geography, is water. It refers to biodiversity and environmental issues, namely the need to preserve the natural environment and encourage the development of sustainable tourism.

As far as the topic of works, the cultural project aims to recall the attention on new forms of work in the era of digitization. The development of new technologies are particularly relevant issues for the future of Europe. With respect to the topic of migration, it does not only refer to migrations of peoples, but to mobility in general which include the concept of exchange and global collaborations. On the official website of Rijeka2020 the mining of migration is recalled as: *'Rijeka is a city of migrations, a city of arrivals and departures, of interconnected cultures and also of tolerance'*.

With regard to Galway, the cultural project is synthetized by the slogan 'Let the Magic in' and it focused on three thematic areas: immigration, landscape and linguistic identity.

As for immigration, a large portion of residents was born outside Ireland and the city was, therefore, encouraged to celebrate the cultural diversity on its territory. The landscape perspective enhances the environmental richness of the city and its admirable balance between rural and maritime scenarios. Regarding the issue of linguistic identity, it refers to the historical tradition to celebrate the Irish Gaelic language of which Galway represents the capital. The entire program was structured on the basis of the ancient pre-Christian Celtic calendar, and related holidays, which divides the year into four parts: Ibmolc (February to April); Beltaine (from May to July); Lughnasa (from August to October); Samhain (November to January 2021).

*4.2 Cultural project limitations and new strategies implemented*

As far as Rijeka is concerned, one could argue that the cultural program as ECoS has been impacted by the pandemic emergence under different perspectives. The analysis of s collected online has enabled to verify how the health emergence has required the interruption of the collaborations activated by Rijeka 2020 Company (established for the preparation and implementation of the ECoC program) which counted 59 employees. To this purpose, the words of the director of the project Emina Višnić stated that (source: www.rijeka2020.eu):

> In the context of the crisis caused by the pandemic together with the City of Rijeka, owner of the CEC program, we have examined different scenarios and opportunities and drafted a new proposal for the implementation plan of the project, which includes a series of measures necessary to adapt to the crisis caused from the pandemic. Unfortunately, we have also been forced to take difficult measures which have led to the reduction of the number of employees to a much needed, smaller team with the possibility of returning to work when the conditions are created.

Despite the limited availability of human resources, Rijeka has continued to implement its cultural program by considering the transformation and adaption required by the lockdown and following the bounded limitations. Specifically, communication with the public and the management of media have been managed through the Media Relations Service of the City of Rijeka, while the Rijeka 2020 Company was in charge of establishing the necessary collaborations for the production of website online contents and social networks of the project.

Limitations to mobility and accessibility have not only impacted on the number of visitors but also on the participation of foreign artists who had previously confirmed their participation. This required a structural revision of the agenda of program. Despite this, Rijeka was determined to implement its cultural project. This is the sense of the words of Vojko Obersnel, Major of the City of Rijeka (source: www.rijeka2020.eu):

> We were stopped at a crucial moment for our culture and art that should have fully demonstrated our link with the richness of diversity and unity with Europe in the messages of acceptance, freedom and openness . . ...We have therefore been forced to make painful decisions to respond responsibly to this crisis. Despite this, we have not given up and we are not giving up on the ECoC project, so we have to look at it in a new way. In this context, I would like to recall the original idea with which Rijeka has access to the candidacy and won the ECoC title for the priceless legacy of the project, which is not manifested only in infrastructures.

The health emergence has impacted also on the cultural project of Galway by requiring a large revision of the program of events, too. The limitations due to the COVID-19 have generated several limitations for the participation in presence of visitors and artist. The program of Galway 2020 has largely shifted to the online mode on the official website of Galway ECoC that immediately became the main channel for the promotion of different initiatives. Among the different initiatives subject to digitalization, there was also the filmed version of Savage Beauty by Finnish artist Kari Kola. The latter, that was made available online, helped people to recall a large number of users by extending the opportunity of participation to a larger audience. In this direction, Helen Marriage, Creative Director of Galway 2020 claimed (source: www.galway2020.ie/en):

> We are very proud of the work that Kari Kola and her team have done to create this wonderful work of art. We were really moved by how the local community welcomed us during this time. Although we have been forced to cancel Savage Beauty's live performances as a result of government restrictions due to the Covid, I am thrilled to be able to share this special digital edition so that as many people as possible will be able to attend this extraordinary work of art.

A further digital proposal recalling a great interest has been the 'Eye on the Edge' (European Youth Event). As a local edition of the biennial meeting held in Strasbourg, the event normally brings together thousands of young people from all over the European Union to share and shape their ideas on the future of Europe.

### *4.3 The role of DT in supporting the achievement of the cultural goals of their programs*

With respect to Rijeka, DT and, mainly, social media have represented the main tool for guaranteeing the implementation of the cultural program of the City. In collaboration with the Media Relation Service of the City, the Rijeka 2020 Company has worked for grasping the benefits of the most popular social media such as Instagram, Twitter, Facebook and YouTube for addressing the interest of the public towards the cultural initiatives already undertaken. For this purpose, the identification of #rijeka2020 as the programme official hashtag has allowed to create commitment and readdressing interested people toward the official website of the Company (www.rijeka2020.eu). DT and web have been also adopted for an active involvement of citizens and visitors in the new programme. Amongst different initiatives, it is possible to mention an online quiz named: *'What's your type of culture?'*, made available in several languages. It was conceived as tool for the creation of a personal profiles and the personalization of the most suitable cultural events. Users were motivated to participate to the quiz and share it on digital platforms given to the presence of symbolic prizes, such as the possibility of obtaining discounts on tickets. A further initiative has regarded the availability of geocaching games, which represent an evolution of the treasure hunt by the application of GPS to promote Rijeka's past, present and future identity and its creative potential assets.

Also for Galway, the digitalization has represented a valid support for overcoming the limitations to accessibility and mobility of visitors and tourists. The digital offering of important events, such as 'Savage Beauty' and 'The Eye on the Edge' has allowed achieving a successful promotion and important cultural targets. According to the organizers, having shifted these events in virtual mode, together with a larger number of minor events, has impacted positively on the cultural spillovers expected by the ECoC programme. The positive effect in terms of users' involvement has been meaningful for the residents that normally risk to be partially interested by the cultural offerings promoted by the ECoC.

A further element of evidence about the effectiveness of the social media promotion is represented by the large audience recalled as well as by a well performing strategy of communication that has interested mainly on Instagram, Facebook and Twitter with a structured and capillary storytelling (see Table 1).

| Subject matter | Sector/ area | Authors | Research title | Research gap |
|---|---|---|---|---|
| Digital transformation | Big social data | Schroeder (2014) | Big data and social media research | Digitalization and its impact on collective cultural events |
| | | Flesch *et al.* (2016) | Big social data analytics of real-world events | |
| | | Hennig *et al.* (2016) | Big social data analytics in consumer behaviour | |
| | | Rahman and Reza (2022) | Systematic Review of Data Analytics in Social Media | |
| | Tourism | Buhalis (2019) | ICT applied to eTourism and smart tourism | |
| | | Zheng *et al.* (2022) | Smart Technology Use Behaviour for Tourism | The effects of digital technologies on communities in terms of resilience and innovation |
| | Culture | Bakhshi and Throsby (2012) | New technologies in cultural institutions | |
| Resilience and digital transformation | Tourism industry | Jayawardana *et al.* (2022) | Digital transformation on hospitality and tourism industry | |
| | | Deb *et al.* (2022) | Tourism Business in the new normal era | |
| | Cultural industry | Holtorf (2018) | Cultural resilience increased through cultural heritage | |

**Source(s):** Author's own creation

**Table 1.** Most useful literature on Digital transformation and resilience of the cultural industry after COVICD-19

The table below (Table 2), describes the impact of measures on communities in terms of resilience and innovation based on the data described. The added value of Table 2 is that is shows main evidence in terms of analytics (about social media analytics are synthetized for the main social networks in terms of followers, number of posts, etc. etc.) are provided for both ECoC (see Table 2) (see Table 3).

| Variables | | Rijeka | Galway |
|---|---|---|---|
| Instagram | Account | @rijeka2020 | @galway2020 |
| | N. of Posts | 1.273 | 1.188 |
| | Followers | 10.5 K | 23.2 K |
| | Main Hashtags and mentions | #rijeka2020 (20.947 mentions) #portofdiversity2020 (2.230 mentions) #europeancapitalofculture2020 (38.065 mentions) | #galway2020 (52.641 mentions) #gaillimh2020 (974 mentions) #galway2020capitalofculture with (1.270 mentions) #LetTheMagicIn (not relevant) |
| Facebook | Account | @rijeka2020 | @galway2020 |
| | Fan | 40.3 K | 61.8 K |
| Twitter | Account | @rijeka2020 | @galway2020 |
| | Followers | 2.4 K | 27.8 K |

**Source(s):** Author's own creation

**Table 2.** Evidence resulting from analytics

| Main features | Rijeka | Galway |
|---|---|---|
| Slogan | 'Port of Diversity' | 'Let the Magic in' |
| Identity Cultural Pillars | Water, Work, Migration | Immigration, Landscape, Linguistic Identity |
| Solutions implemented to overcome the limitations | Strong collaboration between the Media Relation Service of the City and Rijeka 2020 Company<br>Identification of an official # for tagging all the initiatives undertaken and readdressing interested people toward the official web site<br>Development of an online multilingual quiz entitled: 'What's your type of culture?' for personalizing the cultural offering of events – Awards and recognition managed on social media<br>Geocaching games, based on GPS, to promote Rijeka's past, present and future identity and its creative potential assets | Promotion of the official website of Galway2020 as main portal of access to all events<br>Digital setting of important events (i.e. Savage Beauty, Eye on the Edge, etc)<br>Development of a strategy of social media promotion, mainly on Facebook (more than 210.000 posts have been published on the official account of Galway 2020) |
| Main Impact in terms of Innovation and Resilience | Reconfiguration of the calendars of events<br>Limited participation of foreign artists<br>Limited tourist arrivals<br>Limited impact on the employment of Rijeka 2020 Company | Reconfiguration of the calendars of events<br>Larger access to cultural contents and events by residents<br>Limited tourist arrivals |

**Source(s):** Author's own creation

**Table 3.** Synthesis of main evidences that identifies common and specific patterns

The communication campaigns have produced, in both the cases, interesting numbers in terms of commitment. More specifically, Galway has performed better in terms of audiences (followers and fans) on all the three social networks. For Rijeka it is interesting to note the usage of #europeancapitalofculture2020 among the official and hashtags.

Nevertheless, it is important to point out that the information provided in the Table above would become more interesting if viewed over time to the extent that would enable to identify correlations between certain activities and community responses.

### *4.4 Cross-cases analysis*

The analysis of the two cases allows the identification of common and specific patterns.

In Table 2 that follows, main evidence are synthetized in terms of official claim, identity cultural pillars, solutions implemented to overcome the limitations due to the COVID-19, main impact.

The two cultural projects behind the election of Rijeka and Galway as ECoC 2020 include elements that find heat discussion in the current public debate and refers to issue of future development and sustainable growth. The two projects recall into their cultural proposition the distinctive elements of their-own identity and history, but the perspectives from which they aimed to contribute to the creation of a better society, are different. The cultural programme of Rijeka has been synthetized into the claim 'Port of Diversity', with a set of cultural pillars identified into the words 'Water, Work and Migration'. As far as Galway is concerned, the cultural program is read through the lenses of magic that is justified by the claim 'Let the Magic in' and cultural pillars identified into the words 'Immigration, Landscape, Linguistic Identity'.

By focusing on the solutions implemented to manage the limitations imposed by the Covid-19, the Capitals have promoted different initiatives in order to overcome the lockdown and the following phases regarding limited mobility and accessibility. For both of them, the virtualization of events has represented the main solution to limited accessibility of the Capitals that originally presented a rich and differentiated programmes. Specific actions implemented by Rijeka has been related to the reinforcement of the collaboration with the Media Relation City Office and the creation of a structured strategy of social media promotion as well as the launching of two web-based initiatives related to a multi-language survey useful for personalizing the offering of cultural events. The last but not the least, it is interesting to mention the geocaching game based on GPS for the virtual exploration of the city's cultural assets.

With respect to Galway, the strategy implemented in reply to COVID-19 limitations to mobility and accessibility has consisted in the reinforcement of the official web site as the main portal for accessing the rich calendar of events. In particular, the organization of big cultural events, such as Savage Beauty, Eye on the Edge have allowed to recall the interest of a large audience even though those were managed online. This has been possible thanks to the setting of a well-structured strategy of promotion on social media (mainly on Facebook).

Specific patterns can be observed into the management of digital marketing and communication campaigns (Valeri and Baggio, 2020). By focusing on the main analytics made available by the different social networks, it is possible to observe that despite the presence of both ECoC, the performances of virtual cultural experiences promoted are prevalent in Galway.

The cross-cases analysis discloses the main differences in terms of the impact. Focusing on available data, the cross-cases analysis allows to identify some distinctive patterns. Clearly, the pandemic emergence has represented in both the cultural programmes a big limitation. However, the intensity of its effects in terms of innovation and resilience of the local communities depicts different scenarios for both ECoC 2020 with more limited benefits in the case of Rijeka than in Galway.

The interviews available online highlighted that, as far as Rijeka is concerned, the health emergence has impacted negatively on the expected employment opportunities, on the general fruition of cultural events that, even if managed online, produced a limited impact in terms of users' involvement and wellbeing for residents. In a different way, Galway, has demonstrated that the digitalization has been perceived as a mean for achieving a larger audience and creating major opportunities of involvement for residents and external users.

## 5. Conclusions

The paper was aimed to identify the evidences about the contribution of digitalization strategy embraced by the European Capitals of Culture 2020 (ECoC) in replying to the limitations due to COVID-19 emergence. Specifically, the study tried to understand how DT have impacted on their communities by developing resilience and innovation by allowing to derive common and distinctive patterns from the experience of Rijeka and Galway, ECoC 2020. During the Sars-Cov-2 pandemic, following the security measures that led to the closure of cultural events and culture was also quarantined. The unfavourable circumstances, however, had the merit, if one may say so, of stimulating a reflection on the potential of DT for the valorization of cultural heritage under emergency conditions never before experienced.

Both empirical cases have demonstrated that digital transformation has contributed to give citizens a centrality in that process of democratization of the cultural heritage that in the literature in known as participatory turn (Del Baldo and Demartini, 2021). This is a true paradigm shift that implies the partial overcoming of the traditional mediating function performed by museums in favour of the development of forms of co-creation (Olsson *et al.*, 2006) possible thanks to models of integration between the physical and digital environment (Nofal *et al.*, 2017).

The use of DT in the period of the health emergency accompanied and fostered, therefore, the change towards an idea of a participative, accessible interactive and inclusive, helping to configure the web as one of the dimensions in which a museum can exist and evolve, communicate, involve and educate its public, impact on society.

Development, implementation, dissemination of different technological tools, during the pandemic crisis, that have ensured the continuation of the events in both ECoC 2020 take a lot from the operational as well as transformative resilience approach, the expression and demonstration in pragmatic form of the capacity to adapt to new circumstances by still ensuring collective well-being. During COVID-19, resilience in the cultural sector has addressed the impacts generated by the pandemic on the environment, selecting new knowledge tools aimed at saving the cultural industry that would have collapsed, otherwise.

### *5.1 Managerial implications*

Technology-empowered experiences increasingly support us to co-create value throughout all stages of activities (Neuhofer *et al.*, 2014; Fotis *et al.*, 2011).

The objective of the analysis of the two cases has been addressed towards the identification of projects approved with their election at European Capital of Culture, the strategy implemented for overcoming the limitations due to COVID-19, for example the role of DT in supporting the achievement of the cultural goals of their programs. Analysing the challenges and opportunities of digitization in cultural helps to understand how these challenges and opportunities have been discussed and how they could be addressed. For cultural events new technologies open up possibilities for more effective pursuit of organizational goals.

The authors drew from a qualitative investigation of two European Capitals by integrating data from secondary sources and social media big data analytics. Specifically, the analysis of data from secondary sources focused on official reports, press review and online interviews to key actors. While the analysis of social media big data analytics referred to metrics about users' involvement and communicational performances made available by social networks. The study offers several implications also for the practice. By confirming the importance of digitalization defined as 'one of the focal strategic initiatives driving many organizations' veins' (Jayawardana *et al.*, 2022) in the promotion of cultural events, the study suggests elements of novelty for the agenda of policy makers. This is justified in terms of creating double-mode events, building institutional collaborations and promote local stakeholders' engagement, ensuring the sustainability of the cultural offering. Through evidence related to the examination case studies it would be possible to know what types of communication and organizational way are used to promote and valorize the typical aspects of the candidates to ECoCs 2020. Hence, it will be possible to choose whether to reuse them in correct way.

In addition, it could be interesting to verify if and how it would possible to use, in the occasion of next competitions and without the restrictions imposed by COVID-19, the different elements of DT in order to give more value for communities and people. At this stage, it could be interesting to monitor how the more consolidated behaviour in accessing digital events has been acquired into the future programs of SECoC.

Inevitably smart environments transform industry structures, processes, and practices, having disruptive impacts for service innovation, strategy, management and competitiveness of everybody involved. On our view, this requires investment in the capacity of institutions to engage in what has been described as arts R&D (Bakhshi and Throsby, 2012). In order to encourage the pursuit of DT along the lines discussed in this paper, new approaches will be required at innovative projects to be undertaken by the stakeholders.

### 5.2 Limitations and future research

The paper presents some limitations that deserve further examination. Firstly, the methodological approach as well as the nature of data collected suggest the need of future investigation with the inclusion of a larger sample of ECoCs. The article is based on two cases from Croatia and Ireland. Due to time and budget limitations, this study considers a small sample size, cross-sectional study and purposive sampling procedure, whereas a large sample size and longitudinal data collection process provide a better result for understanding and generalized, hence, the results of the study cannot be generalized, these regions (Croatia and Ireland) imply various operates conditions and may not represent all European or global regions. The geographical and sociocultural context may be important in developing and adapting to new strategies of digitalization in practice. Institutional barriers related to the introduction of new digitalization in the tourism sector may vary depending on the context and their 'rigidity' in institutional work. In these countries, a networked and cooperative business culture, as well as a more developed technological infrastructure, may affect the fluidity of these barriers. Secondly, the collection of primary data resulting from interviews, or, in addition, the inclusions of quantitative date related to trends of online cultural experiences and travel data. A third limitation is associated to the theoretical perspective of digitalization assumed as main field of investigation of the study. Despite its actuality, it could be interesting to verify the opportunity of including other perspectives in the investigation of the innovation and resilience capabilities of an ECoC. The future step is the replication of the study with the inclusion of the new ECoCs could allow to better understand how the cultural projects have been modified and, to identify correlations in terms of geography, nature of the cultural events, and local features, for sound understanding. In the meantime, areas for future research could be identified into the application of different methodological approach useful, such as social network analysis, content analysis, for deepening the specific and distinctive patterns.

Since our data consist of a limited number of interviews and because they have an exploratory nature, we call for further research on larger samples in order to claim the generalizability of the study results, a comparative study can be directed on the applications of DT in tourism among European countries and other countries.

Future research can enhance the current conceptual framework by including other relevant variables like negative anticipated emotions at other locations, as the current study was conducted in the Croatian and Irish contexts. Because this topic is promising for further research, we therefore hope that it will serve as inspiration for more studies.

## References

Adger, W.N. (2000), "Social and ecological resilience: are they related?", *Progress in Human Geography*, Vol. 24 No. 3, pp. 347-364, doi: 10.1191/030913200701540465.

Adger, W.N. (2003), "Building resilience to promote sustainability: an agenda for coping with globalisation and promoting justice", International Human Dimensions Programme on Global Environmental Change (IHDP), Newsletter 2, Bonn, Germany.

Akehurst, G. (2009), "User generated content: the use of blogs for tourism organisations and tourism consumers", *Service Business*, Vol. 3 No. 51, doi: 10.1007/s11628-008-0054-2.

Allam, Z. and Newman, P. (2018), "Redefining the smart city: culture, metabolism and governance", *Smart Cities*, Vol. 1 No. 1, pp. 4-25, doi: 10.3390/smartcities1010002.

Allen, C.R., Gunderson, L. and Johnson, A.R. (2005), "The use of discontinuities and functional groups to assess relative resilience in complex systems", *Ecosystems*, Vol. 8 No. 8, pp. 958-966, doi: 10.2307/25053891.

Altig, D., Baker, S., Barrero, J.M., Bloom, N., Bunn, P., Chen, S. and Mihaylov, E. (2020), "Economic uncertainty before and during the COVID-19 pandemic", *Journal of Public Economics*, Vol. 191, 104274, doi: 10.1016/j.jpubeco.2020.104274.

Bakhshi, H. and Throsby, D. (2012), "New technologies in cultural institutions: theory, evidence and policy implications", *International Journal of Cultural Policy*, Vol. 18 No. 2, pp. 205-222, doi: 10.1080/10286632.2011.587878.

Barrett, D. and Twycross, A. (2018), "Data collection in qualitative research", *Evidence Based Nursing*, Vol. 21 No. 3, pp. 63-64.

Batabyal, A.A. (1998), "The concept of resilience: retrospect and prospect", *Environment and Development Economics*, Vol. 3, pp. 235-239.

Bennett, E.M., Cumming, G.S. and Peterson, G.D. (2005), "A systems model approach to determining resilience surrogates for case studies", *Ecosystems*, Vol. 8, pp. 945-957, available at: https://www.jstor.org/stable/25053890

Brand, F.S. and Jax, K. (2007), "Focusing the meaning (s) of resilience: resilience as a descriptive concept and boundary object", *Ecology and Society*, Vol. 12 No. 1, art. 23.

Brigo, F., Bonavita, S., Leocani, L., Tedeschi, G., Lavorgna, L. and Technologies, D. (2020), "Telemedicine and the challenge of epilepsy management at the time of COVID-19 pandemic", *Epilepsy and Behavior*, Vol. 110, 107164, doi: 10.1016/j.seizure.2020.12.024.

Buhalis, D. (2019), "Technology in tourism-from information communication technologies to eTourism and smart tourism towards ambient intelligence tourism: a perspective article", *Tourism Review*, Vol. 75, pp. 267-272, doi: 10.1016/j.seizure.2020.12.024.

Burgess, J. and Bruns, A. (2012), "Twitter archives and the challenges of 'big social data' for media and communication research", *M/C Journal*, Vol. 15 No. 5, doi: 10.5204/mcj.561.

Carpenter, S.R., Walker, B., Anderies, J.M. and Abel, N. (2001), "From metaphor to measurement: resilience of what to what?", *Ecosystems*, Vol. 4 No. 8, pp. 765-781, doi: 10.1007/s10021-001-0045-9.

Corvello, V., De Carolis, M., Verteramo, S. and Steiber, A. (2022), "The digital transformation of entrepreneurial work", *International Journal of Entrepreneurial Behavior and Research*, Vol. 28 No. 5, pp. 1167-1183, doi: 10.1108/IJEBR-01-2021-0067.

Cumming, G.S., Barnes, G., Perz, S., Schmink, M., Sieving, K.E., Southworth, J., Binford, M., Holt, R.D., Stickler, C. and Van Holt, T. (2005), "An exploratory framework for the empirical measurement of resilience", *Ecosystems*, Vol. 8, pp. 975-987, doi: 10.1007/s10021-005-0129-z.

Deb, S.K., Nafi, S. and Valeri, M. (2022), "Promoting tourism business through digital marketing in the new Normal Era: a sustainable approach", *European Journal of Innovation Management*, Vol. 26 No. 4, pp. 365-384, doi: 10.1108/EJIM-04-2022-0218.

Del Baldo, M. and Demartini, P. (2021), "Cultural Heritage through the 'youth eyes': towards participatory governance and management of UNESCO sites", in Demartini, P., Marchegiani, L., Marchiori, M. and Schiuma, G. (Eds), *Cultural Initiatives for Sustainable Development*, Springer, Cham, pp. 293-319, doi: 10.1007/978-3-030-65687-4_14.

Del Vecchio, P., Mele, G., Ndou, V. and Secundo, G. (2018), "Creating value from social big data: implications for smart tourism destinations", *Information Processing and Management*, Vol. 54 No. 5, pp. 847-860, doi: 10.1016/j.ipm.2017.10.006.

Demir, O. (2019), "Digital skills, organizational behavior and transformation of human resources: a review", *Ecoforum Journal*, Vol. 8 No. 1, pp. 1-6.

Dredge, D., Phi, G., Mahadevan, R., Meehan, E. and Popescu, E.S. (2018), "Digitalisation in tourism: in-depth analysis of challenges and opportunities. Low value procedure GRO-SME-17-C-091-A for executive agency for small and medium-sized enterprises (EASME)", Virtual Tourism Observatory. Aalborg University, Copenhagen.

Ducange, P., Pecori, R. and Mezzina, P. (2018), "A glimpse on big data analytics in the framework of marketing strategies", *Soft Computing*, Vol. 22 No. 1, pp. 325-342.

Eisenhardt, K.M. (1989), "Agency theory: an assessment and review", *Academy of Management Review*, Vol. 14 No. 1, pp. 57-74.

Femenia-Serra, F. (2018), "Smart tourism destinations and higher tourism education in Spain. Are we ready for this new management approach?", *Information and Communication Technologies in Tourism*, Springer, Cham, pp. 437-449.

Femenia-Serra, F. and Ivars-Baidal, J.A. (2018), "Do smart tourism destinations really work? The case of Benidorm", *Asia Pacific Journal of Tourism Research*, pp. 1-20, doi: 10.1080/10941665.2018.1561478.

Flesch, R., Vatrapu, R., Mukkamala, R. and Hussain, A. (2015), "Social set visualizer: a set theoretical approach to big social data analytics of real-world events", *Proceedings 2015 IEEE, International Conference on Big Data, Santa Clara, CA, USA, 2015*, pp. 2418-2427.

Folke, C. (2006), "Resilience: the emergence of a perspective for social-ecological system analyses", *Global Environmental Change*, Vol. 16 No. 3, pp. 253-267, doi: 10.1016/j.gloenvcha.2006.04.002.

Fotis, J., Buhalis, D. and Rossides, N. (2011), "Social media impact on holiday travel planning: the case of the Russian and the FSU markets", *International Journal of Online Marketing (IJOM)*, Vol. 1 No. 4, pp. 1-19.

Garzoni, A., De Turi, I., Secundo, G. and Del Vecchio, P. (2020), "Fostering digital transformation of SMEs: a four levels approach", *Management Decision*, Vol. 58 No. 8, pp. 1543-1562, doi: 10.1108/MD-07-2019-0939.

Giovannini, E., Benczur, P., Campolongo, F., Cariboni, J. and Manca, A.R. (2020), "Time for transformative resilience: the COVID-19 emergency", JRC Research Reports JRC120489, Joint Research Centre (Seville site), available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC120489

Govindan, K., Mina, H. and Alavi, B. (2020), "A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: a case study of coronavirus disease 2019 (COVID-19)", *Transportation Research E: Logistics and Transportation Review*, Vol. 138, 101967, doi: 10.1016/j.tre.2020.101967.

Grover, P. and Kar, A.K. (2017), "Big data analytics: a review on theoretical contributions and tools used in literature", *Global Journal of Flexible Systems Management*, Vol. 18 No. 3, pp. 203-229, Springer.

Gunawan, J., Marzilli, C. and Aungsuroch, Y. (2022), "Online 'chatting'interviews: an acceptable method for qualitative data collection", *Belitung Nursing Journal*, Vol. 8 No. 4, pp. 277-279.

Gunderson, L.H. and Pritchard, L. (2002), *Resilience and the Behaviour of Large-Scale Systems*, Island Press, Washington, D.C., USA.

Guryanova, A.V., Smotrova, I.V., Makhovikov, A.E. and Koychubaev, A.S. (2020), "Socio-ethical problems of the digital economy: challenges and risks", in Ashmarina, S., Mesquita, A. and Vochozka, M. (Eds), *Digital Transformation of the Economy: Challenges, Trends and New Opportunities. Advances in Intelligent Systems and Computing*, Springer, Cham, Vol. 908.

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J. and Williams, P. (2010), "Foundations for smarter cities", *IBM Journal of Research and Development*, Vol. 54 No. 4, pp. 1-16.

Hennig, A., A°modt, S., Hernes, H., Nyga°rdsmoen, H.M., Larsen, P.A., Mukkamala, R.R., Flesch, B., Hussain, A. and Vatrapu, R.K. (2016), "Big social data analytics of changes in consumer behaviour and opinion of a TV broadcaster", *Proceedings IEEE, International Conference on Big Data, Washington, DC, USA*, pp. 3839-3848.

Holtorf, C. (2018), "Embracing change: how cultural resilience is increased through cultural heritage", *World Archaeoly*, Vol. 50, pp. 639-650.

Janssen, M.A., Schoon, M.L., Ke, W. and Börner, K. (2006), "Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change", *Global Environmental Change*, Vol. 16 No. 3, pp. 240-252, doi: 10.1016/j.gloenvcha.2006.04.001.

Jayawardana, C., Albattat, A., Valeri, M. and Jaharadak, A.A. (2022), "Technology acceptance ante-cedents in digital transformation on hospitality industry", *International Journal of Hospitality Management*. doi: 10.1016/j.ijhm.2022.103350.

Kagermann, H. (2015), "Change through digitization—value creation in the age of industry 4.0", in Albach, H., Meffert, H., Pinkwart, A. and Reichwald, R. (Eds), *Management of Permanent Change*, Springer Gabler, Wiesbaden. doi: 10.1007/978-3-658-05014-6_2.

Korkmaz, G. and Toraman, Ç. (2020), "Are we ready for the post-COVID-19 educational practice? An investigation into what educators think as to online learning", *International Journal of Technology in Education and Science (IJTES)*, Vol. 4 No. 4, pp. 293-309, doi: 10.46328/ijtes.v4i4.110.

Lee, S.M. and Trimi, S. (2020), "Convergence innovation in the digital age and in the COVID-19 pandemic crisis", *Journal of Business Research*, Vol. 123, pp. 14-22, doi: 10.1016/j.jbusres.2020.09.041.

Leung, R. (2019), "Smart hospitality: Taiwan hotel stakeholder perspectives", *Tourism Review*, Vol. 74 No. 1, pp. 50-62, doi: 10.1108/TR-09-2017-0149.

Massi, M., Vecco, M. and Lin, Y. (2020), *Digital Transformation in the Cultural and Creative Industries*, Routledge, London.

McLoughlin, C. and Lee, M.J.W. (2010), "Personalised and self regulated learning in the Web 2.0 era: International exemplars of innovative pedagogy using social software", *Australasian Journal of Educational Technology*, Vol. 26 No. 1, pp. 28-43, doi: 10.14742/ajet.1100.

Merz, M.A., Zarantonello, L. and Grappi, S. (2018), "How valuable are your customers in the brand value co-creation process? The development of a customer co-creation value (CCCV) scale", *Journal of Business Research*, Vol. 82, pp. 79-89, doi: 10.1016/j.jbusres.2017.08.018.

Neuhofer, B., Buhalis, D. and Ladkin, A. (2014), "A typology of technology-enhanced tourism experiences", *International Journal of Tourism Research*, Vol. 16 No. 4, pp. 340-350.

Nofal, E., Reffat, R. and Vande Moere, A. (2017), "Phygital heritage: an approach for heritage communication", *Conference: Third Immersive Learning Research Network Conference (iLRN2017), Coimbra, Portugal*. doi: 10.3217/978-3-85125-530-0-36.

Noh, S. and Tolbert, P.S. (2019), "Organizational identities of U.S. art museums and audience reactions", *Poetics*, North-Holland, Vol. 72, pp. 94-107.

Olsson, P., Folke, C. and Berkes, F. (2004), "Adaptive co-management for building resilience in social-ecological systems", *Environmental Management*, Vol. 34 No. 1, pp. 75-90, doi: 10.1016/j.jenvman.2015.06.019.

Olsson, P., Gunderson, L.H., Carpenter, S.R., Ryan, P., Lebel, L., Folke, C. and Holling, C.S. (2006), "Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems", *Ecology and Society*, Vol. 11 No. 1, p. 18, doi: 10.5751/ES-01595-110118.

Park, K., Nguyen, M.C. and Won, H. (2015), "Web-based collaborative big data analytics on big data as a service platform", *Proceedings 2015 of the 7th International Conference of Advanced Communication Technology (ICACT), PyeongChang, Republic of Korea, 2015*, pp. 564-567.

Peng, S., Wang, G. and Xie, D. (2016), "Social influence analysis in social networking big data: opportunities and challenges", *IEEE Network*, Vol. 31 No. 1, pp. 11-17.

Petit, O., Velasco, C. and Spence, C. (2019), "Digital sensory marketing: integrating new technologies into multisensory online experience", *Journal of Interactive Marketing*, Vol. 45, pp. 42-61, doi: 10.1016/j.intmar.2018.07.004.

Porter, M.E. and Heppelmann, J.E. (2014), "How smart, connected products are transforming competition", *Harvard Business Review*, Vol. 92 No. 11, pp. 64-88.

Purcell, L.N. and Charles, A.G. (2020), "An Invited Commentary on "World Health Organization declares global emergency: a review of the 2019 novel Coronavirus (COVID-19)": emergency or new reality?", *International Journal of Surgery*, Vol. 76 No. 111, doi: 10.1016/j.ijsu.2020.03.002.

Rabianski, J.S. (2003), "Primary and secondary data: concepts, concerns, errors, and issues", *The Appraisal Journal*, Vol. 71 No. 1, pp. 43-55.

Rahman, S. and Reza, H. (2022), "A systematic review towards big data analytics in social media", *Big Data Mining and Analytics*, Vol. 5, pp. 228-244.

Schroeder, R. (2014), "Big data and the brave new world of social media research", *Big Data Society*, Vol. 1 No. 2, pp. 1-11.

Seetharaman, P. (2020), "Business models shifts: impact of Covid-19", *International Journal of Information Management*, Vol. 54, 102173, doi: 10.1016/j.ijinfomgt.2020.102173.

Shaikh, F., Shaikh, Rangrez, R., Khan, A. and Shaikh, U. (2017), "Social media analytics based on big data", *Proceedings 2017 of the International Conference on Intelligent Control and Computing(I2C2)*, Coimbatore, India.

Strauss, A.L. and Corbin, J. (1990), *Basics of Qualitative Research*, 1st ed, Sage, Thousand Oaks, CA.

Sun, G.-Q., Wang, S.-F., Li, M.-T., Li, L., Zhang, J., Zhang, W. and Feng, G.-L. (2020), "Transmission dynamics of COVID-19 in Wuhan, China: effects of lockdown and medical resources", *Nonlinear Dynamics*, Vol. 101 No. 3, pp. 1981-1993, doi: 10.1007/s11071-020-05770-9.

Svensson, G. and Grönroos, C. (2008), "Service logic revisited: who creates value? And who co-creates?", *European Business Review*, Vol. 20 No. 4, pp. 298-314, doi: 10.1108/09555340810886585.

Thiele, L.P. (2016), *Sustainability*, 2nd ed., Polity Press, Cambridge, UK.

Valeri, M. (Ed.) (2022), *Tourism Risk. Crisis and Recovery Management*, Emerald Publishing, Bingley.

Valeri, M. and Baggio, R. (2020), "Social network analysis: organizational implications in tourism management", *International Journal of Organizational Analysis*, Vol. 29 No. 2, pp. 342-353, doi: 10.1108/IJOA-12-2019-1971.

Vatrapu, R., Mukkamala, R., Hussain, A. and Flesch, B. (2016), "Social set analysis: a set theoretical approach to big data analytics", *IEEE Access*, Vol. 4, pp. 2542-2571.

Volo, S. (2019), "Tourism statistics, indicators and big data: a perspective article", *Tourism Review*, Vol. 75 No. 1, pp. 304-309.

Wang, X., Li, X.R., Zhen, F. and Zhang, J. (2016), "How smart is your tourist attraction?: measuring tourist preferences of smart tourism attractions via a FCEM-AHP and IPA approach", *Tourism Management*, Vol. 54, pp. 309-320.

Yin, R.K. (1994), "Discovering the future of the case study. Method in evaluation research", *Evaluation Practice*, Vol. 15 No. 3, pp. 283-290.

Yin, R.K. (2003), "Design and methods", *Case Study Research*, Vol. 3 No. 9, 2.

Zheng, K., Kumar, J., Kunasekaran, P. and Valeri, M. (2022), "Role of smart technology use behaviour in enhancing tourist revisit intention: the theory planned behaviour perspective", *European Journal of Innovation Management*. doi: 10.1108/EJIM-03-2022-0122.

Zhong, Y.Y.S., Busser, J. and Baloglu, S. (2017), "A model of memorable tourism experience: the effects on satisfaction, affective commitment, and storytelling", *Tourism Analysis*, Vol. 22 No. 2, pp. 201-217, doi: 10.3727/108354217X14888192562366.

## Further reading

Holdgaard, N. and Klastrup, L. (2014), "Between control and creativity: challenging co-creation and social media use in a museum context", *Digital Creativity*, Vol. 25 No. 3, doi: 10.1080/14626268.2014.904364.

Hooper-Greenhill, E. (1999), "Education, communication and interpretation: towards a critical pedagogy in museums", in Hooper-Greenhill, E. (Ed.), *The Educational Role of the Museum, (2nd Edition)*, Routledge, London and New York, pp. 3-27.

Miles, I. and Green, L. (2008), *Hidden Innovation in the Creative Industries*, NESTA Research Report, London.

Olshannikova, E., Olsson, T., Huhtamäki, J. and Kärkkäinen, H. (2017), "Conceptualizing big social data", *Journal of Big Data*, Vol. 4 No. 3, pp. 1-19.

The European Parliament and the Council of the European Union (2020), "Decision No 445/2014/EU of the European parliament and of the council of 16 April 2014 establishing a union action for the

European Capitals of culture for the years 2020 to 2033 and repealing decision No 1622/2006/EC", Official Journal of the European Union.

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G.S., Janssen, M., Lebel, L., Norberg, J., Peterson, G.D. and Pritchard, R. (2002), "Resilience management in social-ecological systems: a working hypothesis for a participatory approach", *Conservation Ecology*, Vol. 6 No. 1, p. 14g, available at: http://www.consecol.org/vol6/iss1/art14/

Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S. and Schultz, L. (2006), "A handful of heuristics and some propositions for understanding resilience in social-ecological systems", *Ecology and Society*, Vol. 11, Art. 13.

Yin, R.K. (2006), "Mixed methods research: are the methods genuinely integrated or merely parallel?", *Research in the Schools*, Vol. 13 No. 1, pp. 41-47.

Yin, R.K. (2008), *Case Study Research: Design and Methods: Applied Social Research Methods*, Sage, London.

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# Perceptions, Strategies, and Challenges of Teachers in the Integration of Artificial Intelligence in Primary Education: A Systematic Review


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## Abstract


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| Aim/Purpose | Evaluate teachers' perceptions, strategies, and challenges in integrating artificial intelligence (AI) into K-12 education and identify patterns and trends in the data from the reviewed studies. |
| Background | This systematic review examines a decade of innovation to explore the transformative impact of AI on education (2014–2024). Adhering to PRISMA 2020 guidelines, the study uncovers key trends, challenges, and breakthroughs in AI-driven teaching and learning, offering a comprehensive perspective on how AI reshapes educational practices and methodologies. |
| Methodology | The study employs a systematic review to analyze the implementation of AI techniques and tools in primary education, following the PRISMA 2020 guidelines to ensure the reliability and effectiveness of the findings. To achieve this, an extensive search was conducted in academic databases such as Web of Science, Scopus, and ERIC, focusing on empirical studies and peer-reviewed articles published between 2014 and 2024. Only accessible, peer-reviewed articles |


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| | classified under Education and Educational Research and published in English or Spanish were selected.<br><br>The search strategy was structured into five categories aligned with the research questions to identify relevant studies accurately. The selection process was carried out in three phases – Identification, Screening, and Inclusion – applying predefined criteria to guarantee the quality and relevance of the selected studies. Of an initial total of 514,919 articles, 488,940 were excluded for not meeting the inclusion criteria. After removing duplicates and evaluating titles, abstracts, and full texts, a final set of 28 studies was included. |
| Contribution | The study explores the integration of AI in primary education, revealing both teachers' enthusiasm and the challenges they face. While AI is perceived as a tool to enhance critical thinking, problem-solving, and student engagement, its implementation is limited by insufficient training, resources, and institutional support.<br><br>Despite these obstacles, teachers show confidence in designing AI-integrated curricula, though this is weakened by inadequate infrastructure and technical support, highlighting the need for continuous professional development. The study also stresses the importance of establishing a competency framework for AI literacy and adopting a systemic approach to AI education.<br><br>Additionally, ensuring safe learning environments by addressing data privacy and AI biases remains a key challenge. Overcoming these issues is essential for the ethical and effective integration of AI, maximizing its benefits while safeguarding student equity and security. |
| Findings | - Educators see the potential of AI to personalize learning.<br>- Barriers are lack of training and resources for teachers.<br>- Importance of continuous training in digital skills.<br>- Need for policies that promote AI literacy.<br>- Collaboration with experts to optimize AI in the classroom. |
| Recommendations for Practitioners | Teachers are encouraged to collaborate in using AI tools to enhance educational outcomes, supported by continuous professional development programs, clear policies that safeguard privacy and promote equality, and a framework that preserves human autonomy in integrating AI technologies. |
| Recommendations for Researchers | The lack of empirical research on AI interventions in education limits understanding of its true impact, highlighting the need for future studies to fill this gap and optimize its application for greater educational benefits. |
| Impact on Society | The integration of AI in K-12 education is not just an opportunity; it is a necessity to prepare future generations for an increasingly digital world. While AI has the potential to revolutionize learning by fostering critical thinking, personalization, and engagement, its impact depends on how effectively it is implemented. To ensure its benefits, it is essential to empower educators and students with AI literacy, address issues like bias and data privacy, and establish robust legal frameworks for fair and transparent use. Without proactive policies, AI could widen educational inequalities instead of reducing them. A responsible, human-centered approach is needed to create an inclusive, ethical, and effective AI-powered education system. |

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| Future Research | The article highlights the urgency of future empirical research to better understand the real impact of AI in education, as the lack of intervention studies limits its optimal application. Analyzing how AI influences learning outcomes, teaching dynamics, equity, and accessibility is essential, along with investigating the pedagogical competencies and technological conditions that affect its adoption. To this end, expanding the scope of studies is recommended by incorporating multicultural and multilingual perspectives, exploring AI applications across various disciplines and educational levels, and promoting interdisciplinary approaches that address ethical, social, and pedagogical dimensions. |
| Keywords | artificial intelligence (AI), elementary education, teaching, professional development and ethics, privacy |

## INTRODUCTION

The role of education is critical in preparing people for the changes driven by Industrial Revolution 4.0. This process requires a focus on developing 21st-century skills and incorporating digital technologies (Elayyan, 2021). Education has evolved to meet diverse learning needs by integrating advanced technologies (X. Chen et al., 2022). The adoption of artificial intelligence (AI) technologies in education has accelerated due to the COVID-19 pandemic, which has revealed both its transformative potential and its limitations and challenges (Grassini, 2023; Mallik & Gangopadhyay, 2023). AI is rapidly transforming various aspects of society, including education. This transformation necessitates a more cosmopolitan approach to education while addressing the challenges teachers face in the era of the Industrial Revolution 4.0 (Elayyan, 2021).

In the context of primary education, the integration of AI presents both opportunities and challenges for teachers. AI assists teachers in planning by facilitating content preparation, designing activities and assessments, and adapting them to the diverse abilities of learners. AI has significant potential to optimize teaching and learning processes through personalization of learning, automated assessment, and intelligent tutoring (Mallik & Gangopadhyay, 2023). From this perspective, AI optimizes various tasks that support the implementation of active and interactive learning models, enriching student learning by making it more meaningful and profound. Rather than restricting its expansion, integrating AI tools into educational settings proves to be a more effective approach (Grassini, 2023). AI has the potential to enhance education across all levels, from preschool to high school, with a particularly positive impact on disadvantaged communities (Pelaez et al., 2022). For instance, Zhang (2024) examined the application of AI in technology education, where an AI system provided continuous feedback to students during the development of a web page. This approach not only improved learning efficiency but also fostered students' autonomous learning skills.

While teachers are generally open to using AI, they face significant challenges that must be addressed to ensure their effective integration into the educational landscape. One of the first challenges is the digital divide and limited access to technology (Sharifuddin & Hashim, 2024). This challenge highlights the importance of inclusive policies that ensure that all schools, regardless of location, have access to technology. Furthermore, the successful integration of AI in the classroom heavily relies on teachers' preparedness and willingness to adapt to these new technologies (K. Kim & Kwon, 2023). Teachers need to be trained in using AI tools to support their teaching tasks. Only through proper training can AI be implemented effectively in classrooms, ensuring that students develop critical and ethical approaches to its use (Y. Chen & Zou, 2024).

On the other hand, AI tools could perform student tasks efficiently and accurately. This highlights a new challenge: redefining the role of learners in this evolving environment, where they must develop new competencies such as critical thinking, creativity, and complex problem-solving skills. Students' use of AI must be balanced carefully to prevent it from diminishing their critical and analytical skills, which are crucial for making informed and ethical decisions about AI (García-Peñalvo et al., 2024). Lee et al. (2023) examined the implementation of an AI translator to support primary school students struggling with English learning. The findings highlighted its positive impact, reducing anxiety and boosting confidence. However, initially, teachers observed an excessive reliance on the tool, which was later moderated, suggesting that overuse could hinder students' autonomy.

Fostering technological self-efficacy in both teachers and students is crucial (Pelaez et al., 2022), and parents' digital literacy plays a key role in supporting student learning (Han et al., 2024). Teacher characteristics and competencies, especially teachers' reflective attitude, self-efficacy, and professional development, significantly influence students' academic performance (López-Martín et al., 2023). Thus, collaboration among stakeholders is vital for addressing challenges and maximizing the opportunities that AI offers in education (Grassini, 2023).

Despite the increasing interest in AI integration in education, significant challenges persist, particularly in primary education. The limited research on contextual differences between urban and rural schools, the scarcity of practical guidance for teachers, and the need for strategies to balance AI use while preserving critical skill development highlight the necessity for further investigation.

Building on these considerations, this study seeks to examine teachers' perceptions, strategies, and challenges in integrating artificial intelligence into primary education. To this end, the systematic review presented in this article is guided by the following primary research question:

- How do teachers perceive, implement, and navigate the challenges associated with integrating artificial intelligence into primary education?

To comprehensively address this central inquiry, the study formulates the following sub-questions to be answered:

- **Q1:** How do teachers perceive AI education in primary education?
- **Q2:** What methods and strategies do primary school teachers use to incorporate AI tools into their educational practice?
- **Q3:** What training have primary school teachers who integrate AI into their teaching practices received, and how do they rate its effectiveness?
- **Q4:** What are the main challenges and constraints faced by primary school teachers in incorporating AI into their teaching?

Building on these research questions, this study seeks to provide a comprehensive understanding of how AI is being integrated into primary education by examining teachers' perceptions, strategies, and challenges. A systematic review aims to identify effective pedagogical approaches, assess the suitability of teacher training programs, and highlight key barriers to the adoption of AI in the classroom. The study contributes to the ongoing discourse on AI in education by addressing these aspects and offering insights that can inform policy, curriculum development, and professional development initiatives. Ultimately, it aims to support the creation of inclusive, effective, and ethically responsible AI-powered learning environments in primary education.

# Literature Review

## *Implementation of Digital Technologies in Education*

The integration of digital curricula in primary education and automated adaptive guidance in K-12 teaching have proven effective in personalizing learning (Gerard et al., 2015; S.-W. Kim, 2023; Leaton, 2020; Rienties et al., 2020; Stringer et al., 2022). However, the effectiveness of these tools largely depends on teachers' digital competence (Consoli et al., 2023), posing specific challenges depending on the educational context.

Teachers face significant barriers to implementing digital technologies (DT) in the curriculum. In rural settings, the lack of technological infrastructure and connectivity limits AI adoption, whereas in underfunded urban schools, the digital divide and the absence of adequate devices hinder effective integration (Stringer et al., 2022). Additionally, insufficient training, a lack of familiarity with DT, and low teacher self-efficacy exacerbate the situation. Dong et al. (2023) point out that different training methods and emotional factors such as attitude, interest, and confidence influence the development of computational thinking (CT). In this regard, S.-W. Kim (2023) highlights the need for further research on how emotions, perceptions, and metaphors shape attitudes toward AI.

Recent case studies further illustrate these challenges. Zhang (2024) analyzed the application of AI in primary and secondary school information courses, emphasizing the need for contextualized approaches to AI integration. Han et al. (2024) explored perspectives from teachers, parents, and students on the use of generative AI in elementary literacy education, revealing concerns regarding its practical implementation and ethical implications. Meanwhile, Sharifuddin and Hashim (2024) conducted a systematic review on the integration of AI in English as a Second Language (ESL) classrooms, highlighting its potential benefits while also identifying key challenges that hinder its effective adoption.

The transition to online teaching has exposed the lack of teacher control over virtual environments and emotional disconnection from students (Pelaez et al., 2022). To overcome these challenges, it is crucial to provide continuous professional development tailored to the specific needs of each educational context (Stringer et al., 2022). Recent studies have shown that CT training enhances digital competencies in pre-service teachers (Dong et al., 2023), while interventions focused on developing pedagogical skills have a direct impact on student academic performance (López-Martín et al., 2023).

Despite advancements in technological integration, there is still no consensus on the appropriate age and approach for introducing DT in primary education (Stringer et al., 2022). Interdisciplinary collaboration is essential to develop a theoretical, empirical, and methodological understanding of the relationship between education and technology (Rienties et al., 2020). Moreover, a regulated and collective approach to AI adoption in education is necessary to ensure social inclusion and equity (Leaton, 2020).

## *Impact of AI on Education*

AI technology must adapt and collaborate with teachers to optimize teaching and learning processes (Pelaez et al., 2022). Human-AI collaboration is essential in this context (X. Chen et al., 2022; Molenaar, 2022). AI can facilitate self-regulated learning through sensing, diagnosis, and action; however, teachers must retain control over the technology (Molenaar, 2022).

Tools like ChatGPT can enhance teaching, research, and student services (Dempere et al., 2023). Nevertheless, despite its potential to personalize education, grade assignments, and provide academic advising, concerns arise regarding the accuracy of AI-generated responses and the possible displacement of the teacher's role (Pradana et al., 2023). While AI can improve learning efficiency, it should not replace teachers (Pua et al., 2021).

Recent studies highlight the need to assess the impact of ChatGPT on learning and to address ethical and legal considerations (Pradana et al., 2023). S.-W. Kim (2023) suggests that it is crucial to design AI education programs specifying content and duration to ensure effective learning. Additionally, Dignum (2021) underscores the importance of preparing individuals for the digital age through responsible AI development.

Empirical research also demonstrates varied outcomes of AI integration in classrooms. Lee et al. (2023) investigated the application of AI translators among low-achieving primary school English learners, finding that while AI tools can enhance engagement, they must be carefully implemented to support pedagogical objectives. García-Peñalvo et al. (2024) analyzed the emergence of generative AI in education, warning of the risks of over-reliance on such technologies without appropriate guidelines for use.

The effective integration of AI in education requires a balanced approach that enhances teaching without replacing teachers. Future research should establish clear guidelines for ethical and pedagogical AI use, while teacher training must prioritize AI literacy. Responsible implementation will maximize AI's potential to personalize learning, support diverse students, and improve teaching in the digital era.

### *Ethical Considerations of AI in Education*

AI governance requires a multidisciplinary approach to address its ethical and social challenges (Dignum, 2021). It is essential to develop regulations and practices that respect pedagogical rights and ensure the fair and transparent use of AI in education (Leaton, 2020).

The impact of AI on teaching and learning underscores the need to consider ethics and accountability in its application within educational contexts (Dignum, 2021). Teachers must be informed about both the benefits and limitations of AI and ensure its implementation follows human-centered principles (Pua et al., 2021). Yan et al. (2024) emphasize the importance of addressing practical and ethical challenges in the development of educational innovations.

Ethical and legal concerns surrounding AI adoption in education must be carefully considered (Mallik & Gangopadhyay, 2023). Online education should be humanized, ensuring effective interaction between AI tools and students (Pelaez et al., 2022). The lack of transparency in the operation of Large Language Models (LLMs) poses a challenge for educational stakeholders, raising risks related to privacy, equity, and data interpretability (Dempere et al., 2023; Gillani et al., 2023; Yan et al., 2024).

Given these challenges, this study aims to provide a comprehensive perspective on the integration of AI in primary education, identifying key factors influencing its adoption and offering recommendations for its effective implementation in various school contexts. Additionally, it analyzes recent case studies of schools attempting to integrate AI into their classrooms, highlighting lessons learned and existing gaps in practical guidance for its application.

## Methodology

To explore the contemporary landscape of the implementation of AI techniques and tools in the pedagogical domain, a systematic review has been conducted covering the period from 2014 to 2024, adhering to the guidelines of the Preferred Reporting Items for Systematic Reviews (PRISMA 2020) (Khan et al., 2022; Page et al., 2021).

To ensure the effectiveness of the systematic review, essential components such as research questions, participants, interventions or exposures compared, outcomes measured, and methodology of the studies have been considered. (Khan et al., 2022). These components have been appropriately structured to anticipate and manage possible variations that may arise during the review process. Page et al. (2021) state that the PRISMA 2020 guideline allows the assessment of the appropriateness of methods and reliability of findings in systematic reviews.

### *Search in Databases*

The following editorial databases were selected to locate empirical studies on the application of AI in teaching in primary classrooms: Web of Science, Scopus, and ERIC. Filters were used for empirical research and peer-reviewed articles in the fields of education and educational research from January 2014 to February 2024.

## *Identification of Search Terms*

Based on the specific requirements of the bibliographic databases, the search strategies were designed to align with the research questions. The search terms were structured into five categories:

1. **Artificial Intelligence and AI applications**: Keywords such as “artificial intelligence” OR “AI” OR “AIED” OR “AI literacy” OR “artificial intelligence literacy” were included.
2. **Education**: Terms related to the educational context, including “education” OR “school” OR “classroom” OR “education system.”
3. **Teaching and pedagogical improvement**: Keywords such as “teaching” OR “teaching behavior” OR “teacher behavior” were used to capture studies on instructional practices.
4. **Educational level**: The search was restricted to primary education, using terms like “primary school” OR “elementary school” OR “K-12” OR “primary education” OR “elementary education.”
5. **Exclusion criteria**: To refine the search, studies referring to higher education were excluded by filtering out terms such as “higher education” OR “college” OR “university” OR “post-secondary” OR “postsecondary.”

This systematic approach allowed for a comprehensive and focused literature search, as shown in Table 1.

**Table 1. Search order applied in databases**

| Database | Search order |
|---|---|
| Web of Science | TS=(artificial intelligence) OR TS=(AI) OR TS=(AIEd) OR TS=(AI literacy) OR TS=(artificial intelligence literacy) AND TS=(EDUCATION) OR TS=(SCHOOL) OR TS=(CLASSROOM) OR TS=(EDUCATION SYSTEM) AND TS=(TEACHING) OR TS=(teaching behavior) OR TS=(teacher behavior) AND TS=(PRIMARY SCHOOL) OR TS=(ELEMENTARY SCHOOL) OR TS=(K-12) OR TS=(PRIMARY EDUCATION) OR TS=(ELEMENTARY EDUCATION) NOT TS=(HIGHER EDUCATION) NOT TS=(COLLEGE) NOT TS=(UNIVERSITY) NOT TS=(POST SECONDARY) NOT TS=(POSTSECONDARY) |
| Scopus | (TITLE-ABS-KEY (artificial AND intelligence) OR TITLE-ABS-KEY (ai) OR TITLE-ABS-KEY (aied) OR TITLE-ABS-KEY (ai AND literacy) OR TITLE-ABS-KEY (artificial AND intelligence AND literacy) OR TITLE-ABS-KEY (a.i.) AND TITLE-ABS-KEY (education) OR TITLE-ABS-KEY (school) OR TITLE-ABS-KEY (classroom) OR TITLE-ABS-KEY (education AND system) AND TITLE-ABS-KEY (teaching) OR TITLE-ABS-KEY (teaching AND behaviour) OR TITLE-ABS-KEY (teacher AND behaviour) AND TITLE-ABS-KEY (primary AND school) OR TITLE-ABS-KEY (elementary AND school) OR TITLE-ABS-KEY (primary AND education) OR TITLE-ABS-KEY (k12) OR TITLE-ABS-KEY (elementary AND education) AND NOT TITLE-ABS-KEY (higher AND education) AND NOT TITLE-ABS-KEY (college) AND NOT TITLE-ABS-KEY (university) AND NOT TITLE-ABS-KEY (post AND secondary) AND NOT TITLE-ABS-KEY (postsecondary) ) |
| Eric | SU (artificial intelligence or ai or a.i.) AND SU (education or school or learning or teaching or classroom or education system) AND SU (primary school or elementary school or primary education or elementary education) NOT SU (higher education or college or university or post-secondary or postsecondary) |

## *Search Criteria*

The search criteria were designed to locate articles that focused on AI applications in education. Following the research objectives, the following inclusion and exclusion criteria were adopted (Table 2).

**Table 2. Search criteria**

| Search criteria | Inclusion | Exclusion |
|---|---|---|
| Period | Published from 2014 to 2024<br>WOS: 512,205<br>SCOPUS: 291<br>ERIC: 2,423 | Studies outside this period |
| Type of literature | Peer-reviewed journal articles<br>WOS: 23,967<br>SCOPUS: 110<br>ERIC: 1,902 | Literature other than peer-reviewed journal articles |
| Accessibility | Full text available<br>WOS: 15,520<br>SCOPUS: 59<br>ERIC: 1,212 | Not accessible |
| Categories | Education & Educational Research (6.11) and Social Science and Computer Science<br>WOS: 1,019<br>SCOPUS: 48 (Social Sciences and Computer Science)<br>ERIC: 1,065 | Learning content is not the same |
| Search by title | WOS: 96<br>SCOPUS: 23<br>ERIC: 371 | Excluding articles whose titles are not in line with the topic in question |
| Language | English and Spanish<br>WOS: 96<br>SCOPUS: 23<br>ERIC: 344 | Excluding articles not written in English or Spanish |
| Import to Mendeley | WOS: 87<br>SCOPUS: 22<br>ERIC: 314 | Excluding duplicates and those not passed due to electronic failure (n= 40) |
| According to the title and abstract | 78 | Excluding articles whose title or abstract did not correspond to the subject in question (n=345) |
| Research design | Studies should report the effects of AI-supported instruction and teaching (n=28) | Studies that do not report on the effects of AI-supported instruction and learning (n=50) |

## *Study Selection Process*

The selection process followed a structured strategy based on the inclusion and exclusion criteria defined in Table 2. It was divided into three phases – Identification, Selection, and Inclusion – ensuring the relevance, quality, and applicability of the selected studies while adhering to the guidelines of the PRISMA, as shown in Figure 1. Below, the specific filters and their impact on the final dataset are detailed:

1. ***Identification,*** the first phase aimed to establish a relevant timeframe for the literature review.
   - **Period:** Studies published between 2014 and 2024 were included to ensure up-to-date literature (*WOS: 512,205; SCOPUS: 291; ERIC: 2,423*). Studies published outside this period were excluded.
2. ***Screening,*** in this phase, additional selection criteria were applied to refine the dataset and ensure the relevance and quality of the included studies.

- **Type of Literature:** Only peer-reviewed journal articles were selected to guarantee scientific rigor (*WOS: 23,967; SCOPUS: 110; ERIC: 1,902*). Non-peer-reviewed sources were excluded (*WOS: 488,238; SCOPUS: 181; ERIC: 521*).
- **Accessibility:** Studies with full-text availability were included to allow for in-depth analysis (*WOS: 15,520; SCOPUS: 59; ERIC: 1,212*). Articles without full-text access were removed (*WOS: 8,447; SCOPUS: 51; ERIC: 690*).
- **Thematic Categories:** Only studies within the fields of **Education, Social Sciences, and Computer Science** were selected (*WOS: 1,019; SCOPUS: 48; ERIC: 1,065*). Articles unrelated to these disciplines were excluded (*WOS: 14,501; SCOPUS: 11; ERIC: 147*).
- **Title-Based Filtering:** Articles whose titles explicitly aligned with the research topic were retained, in general, "use of AI in primary education", (*WOS: 96; SCOPUS: 23; ERIC: 371*), while non-relevant titles were excluded (*WOS: 923; SCOPUS: 25; ERIC: 694*).
- **Language:** Studies in **English and Spanish** were considered to ensure accessibility (*WOS: 96; SCOPUS: 23; ERIC: 344*). Publications in other languages were excluded (*WOS: 0; SCOPUS: 0; ERIC: 27*).
- **Import to Mendeley:** Duplicates and records with electronic import errors (*n=40*) were removed (*WOS: 9; SCOPUS: 1; ERIC: 30*), leading to a refined dataset (*WOS: 87; SCOPUS: 22; ERIC: 314*).

3. ***INCLUSION,*** the final phase focused on ensuring the thematic and methodological alignment of the selected studies with the research objectives.

   - **Title and Abstract Screening:** A detailed review of titles and abstracts was conducted. Articles misaligned with the research topic were discarded, reducing the dataset to **n=78** after excluding *n=345* irrelevant studies.
   - **Research Design:** Only studies that explicitly reported the effects of **AI-supported instruction and teaching** were included **(*n=28*)**. Articles that did not address this aspect were excluded (*n=50*).

The systematic application of these filters allowed us to refine a broad initial data set into a selection of highly relevant studies. The combination of criteria ensured that the final data set was current, scientifically rigorous, accessible, thematically relevant, and methodologically aligned with the study objectives. These measures improve the robustness, replicability, and impact of the research findings, ensuring that the results obtained are robust, replicable, and valuable for advancing knowledge in the field.

## *LIMITATIONS AND BIASES IN THE STUDY SELECTION PROCESS*

While the selection process is rigorous and designed to ensure the relevance of the included studies, the applied filters may have introduced certain limitations and biases. These could affect the representativeness of the final sample and exclude valuable studies that might have enriched the research findings. The following section outlines the potential limitations and biases that may have arisen in this study:

- **Time Range (2014-2024):** Excluding studies before 2014 may omit valuable insights into the historical evolution of AI in primary education.
- **Literature Type (Peer-Reviewed Only):** Restricting selection to peer-reviewed articles excludes other relevant sources like reports, theses, books, and conference papers, potentially biasing findings toward academic journals.
- **Full-Text Accessibility:** Filtering out articles without full-text access may favor commercially available research while excluding significant but less accessible contributions.
- **Thematic Categories (Education, Social Sciences, Computer Science):** This restriction may overlook studies from fields like psychology, engineering, or cognitive sciences that could provide valuable perspectives on AI in education.

- **Language Filter (English and Spanish):** Excluding studies in other languages (e.g., French, German, Chinese) may introduce linguistic bias and limit the diversity of perspectives.
- **Title and Abstract Screening:** Filtering based on these sections may lead to the omission of relevant studies that do not explicitly reflect their full scope in the title or abstract.
- **Mendeley Import and Duplicate Removal:** Eliminating duplicate records and import errors may inadvertently exclude relevant studies, particularly those stored across multiple databases.

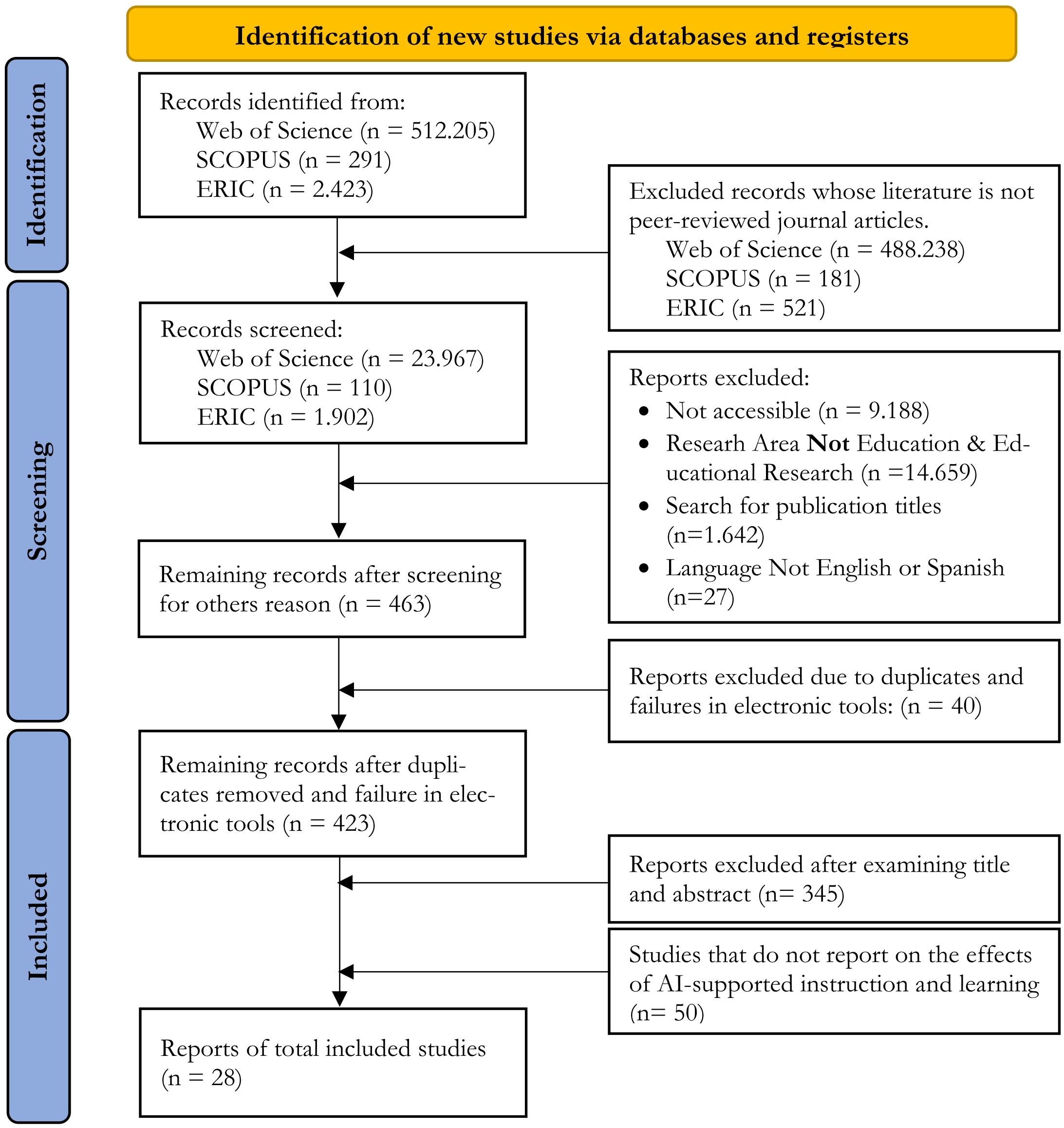


**Figure 1. PRISMA diagram**

## RESULTS

After detailing and analyzing the search methodology, 28 selected articles were reviewed to identify patterns within the collected data. To facilitate this analysis, visual representations, including graphs, were created to highlight key data such as research designs, publication years, and the number of articles addressing each research question. These visual tools enabled a better understanding of the findings and helped identify relevant trends in the selected studies.

The studies employed a variety of research designs: 16 articles utilized qualitative methods, 8 adopted quantitative approaches, and 4 employed mixed methods designs. Notably, 92.8% of the articles in this systematic review were published within the last three years, highlighting the topic's contemporary relevance (Figure 2).

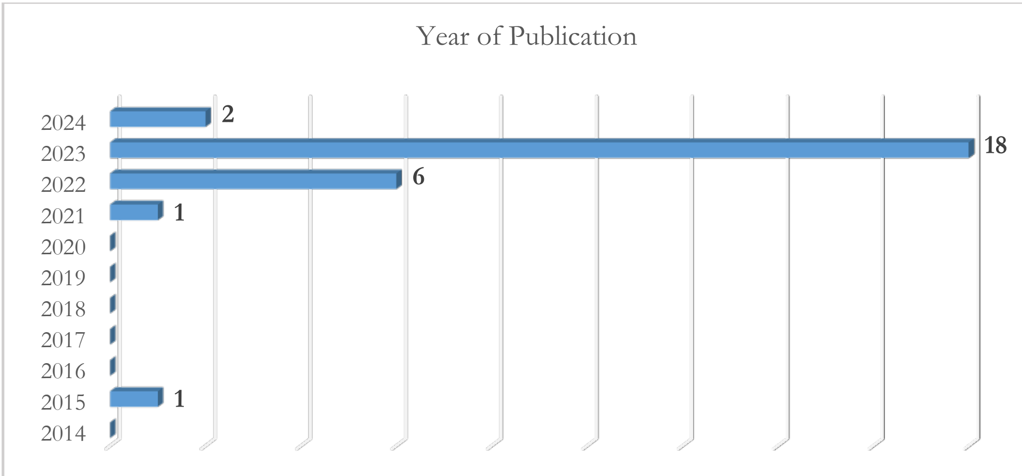


**Figure 2. Publication year of selected studies**

Articles published in 2014 and from 2016 to 2020 were excluded from this review, as no publications specifically addressed the research questions outlined in the study. Although some relevant articles were identified, they focused exclusively on higher education contexts, which fell outside the scope of this investigation. This exclusion was crucial to ensure that the analysis remained aligned with the research objectives.

To provide an in-depth interpretation of the data, the articles were analyzed about the research questions, resulting in the identification, construction, and discussion of codes and categories emerging from the 28 studies (Figure 3). It is important to note that a single article may address multiple research questions, contributing to a broader understanding of the themes analyzed.

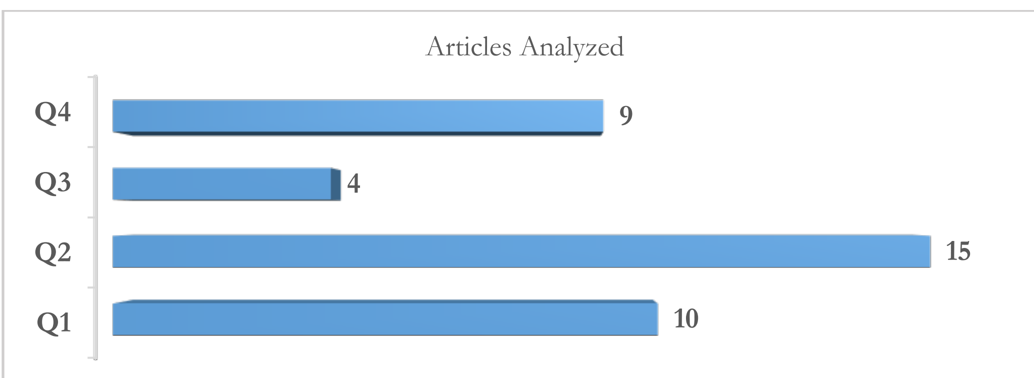


**Figure 3. Number of articles analyzed by the research question**

As a result of this analysis, a table was created summarizing the key findings for each research question (Annexes A, B, C, and D). While the annexes provide a more detailed and comprehensive breakdown of the information, the results have been condensed in Tables 3, 4, 5, and 6 to facilitate a clearer understanding of the main findings.

**Table 3. Summary of the main findings of research question Q1**

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 1 | Q1-Q2 | An, X., Chai, C. S., Li, Y., Zhou, Y., Shen, X., Zheng, C., & Chen, M. (2023). | Modeling English teachers' behavioral intention to use artificial intelligence in middle schools. | To investigate the perceptions, knowledge, and intended use of AI by English as a foreign language (EFL) teachers in secondary education.<br>To examine factors influencing EFL teachers' intention to use AI in education. | EFL teachers have positive perceptions toward the use of AI in teaching, with Performance Expectancy and knowledge of AI-TPACK as influential factors in their intention to use it.<br>Teachers' knowledge of AI-TPACK significantly predicts their intention to use it. Other factors, such as technological knowledge of the AI language and enabling conditions, are also influential. |
| 2 | Q1-Q2 | Benvenuti, M., Cangelosi, A., Weinberger, A., Mazzoni, E., Benassi, M., Barbaresi, M., & Orsoni, M. (2023). | Artificial intelligence and human behavioral development: A perspective on new skills and competencies acquisition for the educational context. | Explore how digitization and artificial intelligence can promote 21st-century skills such as creativity, critical thinking, problem-solving, and computational thinking in educational contexts. | Integrating computational thinking, programming, and coding into school curricula is essential. Creativity can enhance computational thinking, and AI can foster creativity. Critical thinking is crucial for problem-solving and can be enhanced through computational thinking and programming with the help of AI. |
| 3 | Q1-Q2 | Casal-Otero, L., Catala, A., Fernandez-Morante, C., Taboada, M., Cebreiro, B., & Barro, S. (2023) | AI literacy in K-12: A systematic literature review. | Understand how artificial intelligence is being integrated into K-12 education globally, identifying learning experience approaches and theoretical perspectives. | A growing interest in IA education in K-12 schools was identified, with a variety of approaches to teaching IA concepts to students. |
| 4 | Q1 | Chalmers, C., Keane, T., Boden, M., & Williams, M. (2022). | Humanoid robots go to school. | To explore teachers' perceptions of the use of humanoid robots in the classroom and how they can enhance curriculum and student engagement. | Teachers reported benefits in the use of robots for student engagement and learning, highlighting innovation, creativity, and computational thinking. |
| 5 | Q1 | Chen, S., Qiu, S., Li, H., Zhang, J., Wu, X., Zeng, W., & Huang, F. (2023). | An integrated model for predicting pupils' acceptance of artificially intelligent robots as teachers. | To investigate the acceptance of an AI teacher among primary school students in China, identify factors that influence this acceptance, and explore the role of technology in education. | Student acceptance of the AI teacher was moderate. The factors most influencing acceptance were perceived usefulness, ease of use, and task characteristics. Previous experience with IA teachers also affects acceptance. |

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 6 | Q1 | Gerard, L., Matuk, C., McElhaney, K., & Linn, M. C. (2015). | Automated, adaptive guidance for K-12 education. | Investigate the effectiveness of automated, adaptive guidance in K-12 education compared to traditional teacher-directed instruction. To explore specific features of automated guidance that enhance student learning. | Automated, adaptive guidance is generally as effective or more effective than traditional instruction in improving student learning outcomes. Enhanced guidance (with detailed feedback or motivational scaffolding) is more effective than simpler forms of guidance. |
| 7 | Q1-Q3 | El Hajj, M., & Harb, H. (2023). | Rethinking education: An in-depth examination of modern technologies and pedagogic recommendations | Explore the integration of technology in education through the Technological Pedagogical Content Knowledge (TPCK) framework, emphasizing student-centered learning. Identify technological tools that facilitate interactive and engaging teaching strategies. | Technology-based education improves student learning by integrating technological tools into the teaching and learning process. Technology tools such as Tricider, AnswerGarden, and MindMeister, among others, can be used to facilitate teaching strategies such as flipped classrooms, inquiry-based learning, and peer feedback. |
| 8 | Q1-Q2 | Kim, J., Lee, H., & Cho, Y. H. (2022). | Learning design to support student-AI collaboration: Perspectives of leading teachers for AI in education | Explore the integration of Artificial Intelligence (AI) in education, focusing on student-AI collaboration and how this can improve learning in K-12 schools. | Teachers view student-AI collaboration as a tool for achieving optimal learning objectives, emphasizing the importance of knowledge construction, interdisciplinary learning, authentic problem-solving, and creative assignments. |
| 9 | Q1-Q2 | Lim, E. M. (2023). | The effects of pre-service early childhood teachers' digital literacy and self-efficacy on their perception of AI Education for young children | To examine the relationship between digital literacy, self-efficacy, and perceptions of AI (Artificial Intelligence) education for young children among prospective early childhood education teachers. | The means of digital literacy, self-efficacy, and perception of AI education were 3.43, 3.31, and 3.36 respectively, indicating a positive relationship between these variables. Self-efficacy measured the relationship between digital literacy and perception of AI education. |
| 10 | Q1 | Sanusi, I. T., Ayanwale, M. A., & Chiu, T. K. F. (2024). | Investigating the moderating effects of social good and confidence on teachers' intention to prepare school | To examine factors influencing teachers' intention to teach artificial intelligence (AI) in schools, including anxiety toward AI, perceived usefulness, atti- | AI relevance was the most significant predictor of intention to teach AI. Perception of AI for social good and confidence in teaching AI had significant impacts on the intention to teach AI. |

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| | | | students for artificial intelligence education. | tude toward AI, AI relevance, AI readiness, and behavioral intention. In addition, to investigate the moderating effects of AI for social good and confidence in teaching AI. | |

## *Q1. Teacher Perceptions of K-12 AI Education*

The integration of artificial intelligence (AI) in education is transforming teaching and learning processes, particularly through its role in enhancing critical thinking and problem-solving skills (Benvenuti et al., 2023). Faculty members recognize that previous experience with similar technologies influences acceptance (S. Chen et al., 2023), while technology-based education optimizes learning by integrating digital tools into teaching (El Hajj & Harb, 2023). However, the implementation of AI varies depending on the educational context, particularly between urban and rural schools.

Urban schools, with greater infrastructure and access to resources, facilitate AI integration more effectively, whereas rural schools face technological and training limitations that hinder adoption (Casal-Otero et al., 2023; El Hajj & Harb, 2023). This disparity extends to AI tools: humanoid robots, which are costly, are more common in urban settings, while AI-based educational software is more accessible and widely used in both contexts (Chalmers et al., 2022). Furthermore, AI-driven personalized learning is constrained in rural areas due to limited connectivity and device availability (Gerard et al., 2015).

AI-enhanced guidance plays a crucial role in conceptual learning and strategy development (Gerard et al., 2015). Automated guidance benefits students with low to medium prior knowledge (Chalmers et al., 2022) and can be as effective as, or even more effective than, traditional instruction (Gerard et al., 2015). Teachers also perceive humanoid robots as beneficial for student engagement and skill development (Chalmers et al., 2022). Advanced guidance strategies incorporating detailed feedback and motivational scaffolding improve learning outcomes, surpassing simpler instructional approaches (Gerard et al., 2015).

Teachers highly value student-AI collaboration in learning. AI serves as a "learning partner," providing instructional scaffolding and fostering effective collaboration (J. Kim et al., 2022). Educators emphasize AI's role in knowledge construction, interdisciplinary learning, problem-solving, and creative tasks, while factors such as ease of use and task characteristics are deemed less influential (S. Chen et al., 2023). These perspectives align with broader trends in teacher attitudes toward AI adoption.

Studies indicate that elementary school teachers generally hold positive attitudes toward AI in education (An et al., 2023). Digital literacy and self-efficacy mediate their perceptions, reinforcing confidence in teaching AI (Lim, 2023). Expected performance benefits and knowledge levels significantly impact teachers' intent to adopt AI (An et al., 2023), though concerns persist regarding its long-term impact on education (Sanusi et al., 2024). Factors such as self-esteem, expected benefits, and perceived ease of use also shape attitudes toward AI integration in teaching (Nja et al., 2023).

The selection of AI tools is influenced by perceived usefulness, ease of use, and task characteristics, with prior experience playing a key role (S. Chen et al., 2023). Curriculum design that incorporates AI-based learning experiences strengthens teacher confidence in using such technologies (K. Kim & Kwon, 2023). Furthermore, teachers' confidence and recognition of AI's relevance for social good significantly impact their willingness to integrate AI into their teaching practices (Ayanwale et al., 2022; Sanusi et al., 2024). This underscores the need for professional development programs to enhance teachers' AI-related competencies (Lim, 2023).

Overall, AI adoption in education is shaped by contextual factors, pedagogical perceptions, and technological accessibility. Addressing disparities in training opportunities and infrastructure, particularly in rural settings, is crucial for equitable AI integration.

A key real-life example of these trends is the use of humanoid robots in classrooms to foster student engagement and creativity, as observed in the study by Chalmers et al. (2022). This study shows how technology can transform the learning environment and motivate students in innovative ways.

**Table 4. Summary of the main findings of research question Q2**

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| | Q1-Q2 | An, X., Chai, C. S., Li, Y., Zhou, Y., Shen, X., Zheng, C., & Chen, M. (2023). | Modeling English teachers' behavioral intention to use artificial intelligence in middle schools | To investigate the perceptions, knowledge, and intended use of AI by English as a foreign language (EFL) teachers in secondary education.<br>To examine factors influencing EFL teachers' intention to use AI in education. | EFL teachers have positive perceptions toward the use of AI in teaching, with Performance Expectancy and knowledge of AI-TPACK as influential factors in their intention to use it.<br>Teachers' knowledge of AI-TPACK significantly predicts their intention to use it. Other factors, such as technological knowledge of the AI language and enabling conditions, are also influential. |
| 2 | Q2-Q4 | Ayanwale, M. A., Sanusi, I. T., Adelana, O. P., Aruleba, K. D., & Oyelere, S. S. (2022). | Teachers' readiness and intention to teach artificial intelligence in schools | To explore the factors influencing teachers' intention to teach artificial intelligence (AI) in schools and to understand teachers' willingness to implement AI in education. | Factors such as AI literacy, confidence in learning, and AI relevance were significant predictors of behavioral intention. Confidence in teaching AI and AI relevance significantly predicted teachers' intention to teach AI. |
| 3 | Q1-Q2 | Benvenuti, M., Cangelosi, A., Weinberger, A., Mazzoni, E., Benassi, M., Barbaresi, M., & Orsoni, M. (2023). | Artificial intelligence and human behavioral development: A perspective on new skills and competencies acquisition for the educational context. | Explore how digitization and artificial intelligence (AI) can promote 21st-century skills such as creativity, critical thinking, problem-solving, and computational thinking in educational contexts. | Integrating computational thinking, programming, and coding into school curricula is essential. Creativity can enhance computational thinking, and AI can foster creativity. Critical thinking is crucial for problem-solving and can be enhanced through computational thinking and programming with the help of AI. |

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 4 | Q2-Q4 | Bozkurt, A. (2023) | Generative Artificial Intelligence (AI) powered conversational educational agents: The inevitable paradigm shift | Explore the use and impact of generative artificial intelligence, with a focus on ChatGPT, in education. | Generative artificial intelligence, especially ChatGPT, has significant potential to transform teaching and learning methods. |
| 5 | Q1-Q2 | Casal-Otero, L., Catala, A., Fernandez-Morante, C., Taboada, M., Cebreiro, B., & Barro, S. (2023) | AI literacy in K-12: A systematic literature review | Understand how artificial intelligence (AI) is being integrated into K-12 education globally, identifying learning experience approaches and theoretical perspectives. | A growing interest in IA education in K-12 schools was identified, with a variety of approaches to teaching IA concepts to students. |
| 6 | Q2 | Chichekian, T., & Benteux, B. (2022) | The potential of learning with (and not from) artificial intelligence in education | Explore the potential of artificial intelligence (AI) in education, focusing on the effectiveness of AI-driven technologies, the role of teachers, and contributions to the field of education. | Most research focuses on the optimization of AI systems rather than on the quality of learning outcomes. The need for more theoretical investigations and a pedagogical perspective in AI research in education is emphasized. |
| 7 | Q2 | Dimitriadou, E., & Lanitis, A. (2023). | A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in smart classrooms | Explore the role of artificial intelligence (AI) and other emerging technologies in smart classrooms, highlighting both the benefits and challenges of their use in education. | Enhance the learning experience by supporting interactive experiences and real-time feedback. Increased student and teacher engagement and performance through technologies such as VR/AR and robotics. Identification of challenges such as equipment costs needs for teacher training, data privacy concerns, and biases in AI systems. |
| 8 | Q2 | Gentile, M., Città, G., Perna, S., & Allegra, M. (2023). | Do we still need teachers? Navigating the paradigm shift of the teacher's role in the AI era | Examine the changing role of teachers in the age of artificial intelligence (AI) and propose a manifesto to guide this evolution. | A need for teachers to adapt to new technologies and teaching methods. IA is transforming teacher-student relationships and teaching methods. |

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 9 | Q2 | Karalekas, G., Vologiannidis, S., & Kalomiros, J. (2023). | Teaching machine learning in K-12 using robotics | Discuss the importance of and approaches to integrating educational robotics and ML in K-12 education. | Identification of tools and platforms such as Scratch, Cognimates, Teachable Machine, and TensorFlow Playground. Presentation of six AI-powered educational robots: Zumi, RoboMaster S1, ClicBot, Cozmo, MINDSTORMS Robot Inventor, and Cogbots. |
| 10 | Q1-Q2 | Kim, J., Lee, H., & Cho, Y. H. (2022). | Learning design to support student-AI collaboration: Perspectives of leading teachers for AI in education | Explore the integration of Artificial Intelligence (AI) in education, focusing on student-AI collaboration, and how this can improve learning in K-12 schools. | Teachers view student-AI collaboration as a tool for achieving optimal learning objectives, emphasizing the importance of knowledge construction, interdisciplinary learning, authentic problem-solving, and creative assignments. |
| 11 | Q2-Q4 | Kim, K., & Kwon, K. (2023). | Exploring the AI competencies of elementary school teachers in South Korea | To explore the experiences of elementary school teachers in South Korea teaching AI curricula and identify the competencies needed for effective implementation of AI education. | Twenty-two AI competencies were identified for elementary school teachers based on the TPACK framework. Teachers felt most confident in their pedagogical knowledge, followed by technological knowledge and content knowledge. |
| 12 | Q1-Q2 | Lim, E. M. (2023). | The effects of pre-service early childhood teachers' digital literacy and self-efficacy on their perception of ai education for young children | To examine the relationship between digital literacy, self-efficacy, and perceptions of AI (Artificial Intelligence) education for young children among prospective early childhood education teachers. | The means of digital literacy, self-efficacy, and perception of AI education were 3.43, 3.31, and 3.36, respectively, indicating a positive relationship between these variables. Self-efficacy measured the relationship between digital literacy and perception of AI education. |
| 13 | Q2-Q4 | Nazaretsky, T., Ariely, M., Cukurova, M., & Alexandron, G. (2022). | Teachers' trust in AI-powered educational technology and a professional development program to improve it | Improve teachers' confidence in AI technology through a professional development program. | Teachers showed an increase in confidence toward AI technology in education, leading to a greater willingness to use AI tools in their classrooms. |
| 14 | Q2 | Ng, D. T. K., Lee, M., Tan, R. J. Y., Hu, X., Downie, J. S., | A review of AI teaching and learning from 2000 to 2020. | Analyze trends in AI teaching and learning (AITL) research. | The most significant results of the study include the identification of methods and areas of study in AITL, and the analysis of |

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| | | & Chu, S. K. W. (2023). | | | trends and effects on education. The importance of understanding trends in AITL to improve the teaching and learning of artificial intelligence was confirmed. Notable trends were observed in the methodology used, fields of study addressed, and effects on education, suggesting growth and evolution in AITL research over time. |
| 15 | Q2 | Nja, C. O., Idiege, K. J., Uwe, U. E., Meremikwu, A. N., Ekon, E. E. E., Erim, C. M., Ukah, J. U., Eyo, E. O., Anari, M. I., & Cornelius-Ukpepi, B. U. (2023). | Adoption of artificial intelligence in science teaching: From the vantage point of the African science teachers | Explore the use of technology in education, including artificial intelligence, online learning environments, and the uptake of ICT by different age groups. Highlight factors influencing technology adoption by teachers and the impact on student learning outcomes. | The most significant results of the study include the fact that self-esteem, expected benefits, and ease of use significantly impact teachers' attitudes toward the use of artificial intelligence in science teaching. In addition, teachers' location of residence was found to not influence their intention to use artificial intelligence in teaching. Overall, it was confirmed that science teachers show high approval toward the integration of artificial intelligence in the science classroom. No significant differences in the results were observed as a function of teachers' gender, age, or location of residence. |

## *Q2. Methods and Strategies for Incorporating AI Tools Into Teaching Practice*

Effective integration of technology in education is essential, particularly in the case of artificial intelligence (AI). Training teachers in AI and digital competencies is critical to ensuring its effective incorporation into pedagogical practices (Gentile et al., 2023; Nja et al., 2023). However, the extent of AI adoption varies significantly depending on factors such as infrastructure, resource availability, and teacher training opportunities, particularly when comparing urban and rural schools.

Urban schools, with greater access to infrastructure and funding, more easily implement AI-based educational tools. In contrast, rural schools face technological limitations and restricted access to teacher training, which hinders AI adoption (Karalekas et al., 2023; Nja et al., 2023). These disparities influence the types of AI tools utilized. For instance, platforms such as Scratch and Teachable Machine, which enhance STEM education, are widely used due to their accessibility. Schools with greater resources, however, often adopt more advanced AI solutions, while others rely on simpler, cost-effective alternatives (Karalekas et al., 2023).

To address these disparities, methods and strategies for AI integration must focus on designing curricula that foster AI literacy and experiential learning. Educators must update teaching approaches to responsibly incorporate AI, leveraging hands-on activities and interdisciplinary learning (Bozkurt et al., 2023; K. Kim & Kwon, 2023; Nazaretsky et al., 2022). The combination of traditional teaching methods with AI technologies can enhance student engagement and learning outcomes (Dimitriadou & Lanitis, 2023).

In primary education, AI integration is driven by teacher training and competency development. The research underscores the importance of professional development programs that strengthen AI literacy, digital skills, and self-efficacy (Casal-Otero et al., 2023; K. Kim & Kwon, 2023; Nja et al., 2023). Furthermore, AI education policies must be formulated to support curriculum design, teacher capacity building, and a culture of collaborative learning (J. Kim et al., 2022).

The role of computational thinking, programming, and coding in AI education is crucial (Benvenuti et al., 2023). Pedagogical strategies like collaborative and project-based learning enhance AI integration and foster problem-solving skills. Creativity can also strengthen computational thinking, with AI tools supporting innovative learning experiences (Benvenuti et al., 2023; Ng et al., 2023). For example, teachers using humanoid robots report increased student engagement and the development of 21st-century skills (Chalmers et al., 2022).

AI adoption is also influenced by teachers' perceptions and expectations. Studies indicate that performance expectancy, AI-TPACK knowledge, and self-efficacy play a crucial role in educators' willingness to integrate AI into their teaching (An et al., 2023; Sanusi et al., 2024). However, psychological factors, such as anxiety about AI's future role in education, can hinder its adoption (Lim, 2023; Sanusi et al., 2024). Instructors teaching EFL, for instance, show a positive attitude toward AI, influenced by their expectations of its effectiveness and their familiarity with AI pedagogical tools (An et al., 2023).

To optimize AI integration in education, transparency in AI decision-making and teacher control over AI tools are essential (Nazaretsky et al., 2022). Targeted professional development, ongoing support, and competency frameworks can help educators navigate AI-driven education effectively (Casal-Otero et al., 2023). Digital literacy, particularly in prompt engineering, should also be emphasized to enable effective interaction with AI technologies (Bozkurt, 2023).

The implications of these findings highlight the importance of tailoring AI education to different learning contexts and balancing AI implementation with traditional teaching methodologies. By ensuring equitable access to AI resources and professional training, education systems can better prepare teachers and students for the transformative role of AI in the classroom (Bozkurt, 2023; Chichekian & Benteux, 2022).

**Table 5. Summary of the main findings of research question Q3**

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 1 | Q3 | Cheng, E. C. K., & Wang, T. (2023). | Leading digital transformation and eliminating barriers for teachers to incorporate artificial intelligence in basic education in Hong Kong | Exploring the impact of digital leadership on the integration of Artificial Intelligence in Education (AIED), with a focus on overcoming teacher barriers. | Digital leadership significantly predicts all three approaches to AI application in education, while internal teacher barriers negatively predict learning about AI. |

| Nº. | Ques-tion | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 2 | Q3 | Dai, Y., Lin, Z., Liu, A., Dai, D., & Wang, W. (2024). | Effect of an analogy-based approach of artificial intelligence pedagogy in upper primary schools | Develop a scenario-based instrument to assess co-design expertise in humanitarian engineering and explore the use of analogies and metaphors in science education. In addition, investigates the teaching of artificial intelligence (AI) in K-12 classrooms and the importance of AI literacy. | Teaching IA using a pedagogical approach that demystifies IA and uses analogies significantly improves students' understanding, performance, and interest in IA. Students who learned with the analogy-based approach outperformed those with conventional instruction in IA knowledge, skills, and ethical awareness. |
| 3 | Q1-Q3 | El Hajj, M., & Harb, H. (2023). | Rethinking education: An in-depth examination of modern technologies and pedagogic recommendations | Explore the integration of technology in education through the Technological Pedagogical Content Knowledge (TPCK) framework, emphasizing student-centered learning.<br>Identify technological tools that facilitate interactive and engaging teaching strategies. | Technology-based education improves student learning by integrating technological tools into the teaching and learning process.<br>Technology tools such as Tricider, AnswerGarden, MindMeister, among others, can be used to facilitate teaching strategies such as flipped classrooms, inquiry-based learning, and peer feedback. |
| 4 | Q3 | Yau, K. W., Chai, C. S., Chiu, T. K. F., Meng, H., King, I., & Yam, Y. (2023) | A phenome graphic approach on teacher conceptions of teaching Artificial Intelligence (AI) in K-12 schools | To investigate teachers' conceptions of teaching Artificial Intelligence (AI) in K-12 schools using a phenome graphic approach. | The most significant results of the study include the identification of 6 categories of conceptions of Artificial Intelligence (AI) teaching in teachers.<br>These categories cover aspects such as technological bridging, knowledge delivery, stimulation of interest, establishment of ethics, cultivation of skills, and intellectual development. |

## *Q3. Teacher Training in AI and Assessment of Its Effectiveness in Classroom Integration*

The effective integration of AI in education requires professional training, strengthening specific AI knowledge, and fostering a positive perception of its usefulness among teachers (An et al., 2023; Casal-Otero et al., 2023). Understanding teachers' diverse perspectives is essential to improving AI teaching in educational settings, as well as developing training programs that encourage a deeper pedagogical approach (K. Kim & Kwon, 2023; Lim, 2023; Yau et al., 2023).

Teachers' conceptions of AI education fall into six key categories: technological bridging, knowledge delivery, interest stimulation, ethical establishment, skill cultivation, and intellectual development (Yau et al., 2023). These perspectives significantly influence classroom practices and student learning (Chichekian & Benteux, 2022; Lim, 2023), underscoring the need to align professional development programs with these pedagogical conceptions. AI is recognized as a tool for fostering creativity, critical thinking, and problem-solving (Benvenuti et al., 2023). Performance expectancy and AI knowledge are strong predictors of teachers' intention to adopt AI, while effort expectancy does not directly influence their willingness to integrate it (An et al., 2023).

Different instructional strategies have been explored to enhance AI education, such as using analogies to facilitate comprehension, which suggests treating AI as an interdisciplinary subject rather than a standalone field (Dai et al., 2024). Furthermore, AI-driven tools like robot tutors and virtual reality contribute to personalized and collaborative learning experiences (Benvenuti et al., 2023). The role of educators is critical in guiding AI implementation, ensuring its ethical and effective integration into curricula (El Hajj & Harb, 2023; Nazaretsky et al., 2022).

Continuing professional development and training programs should focus on equipping teachers with AI knowledge and practical applications while emphasizing human agency in AI-assisted learning environments (El Hajj & Harb, 2023). Confidence-building and relevance-centered training programs can further support AI adoption (Ayanwale et al., 2022). Digital leadership also plays a crucial role in overcoming barriers to AI integration in education (Cheng & Wang, 2023).

Given the increasing role of AI in education, it is imperative to foster co-evolutionary learning, where students engage with AI in three ways: learning about AI, learning from AI, and learning alongside AI (J. Kim et al., 2022). The interconnectedness of creativity, computational thinking, and critical thinking is fundamental to achieving meaningful learning outcomes (Benvenuti et al., 2023). Consequently, AI education should be systematically incorporated into K-12 curricula, treating AI literacy as a core competency (Cheng & Wang, 2023). Teachers who have undergone AI training exhibit higher confidence and efficacy in integrating AI into their teaching practices (Nazaretsky et al., 2022; Sanusi et al., 2024), with AI literacy and perceived relevance acting as strong predictors of their behavioral intentions (Casal-Otero et al., 2023; Chalmers et al., 2022; Lim, 2023). AI adoption in schools varies depending on infrastructure and resources. With better access to technology and teacher training, urban schools integrate AI more easily, while rural schools face technological and training limitations (Karalekas et al., 2023; Nja et al., 2023). The availability of connectivity and devices also determines the feasibility of personalized AI-driven learning (Gerard et al., 2015).

In primary education, teacher training and competency development are central to AI integration. Digital literacy, curriculum updates, and active pedagogical strategies are emphasized as essential elements for effective AI adoption (Casal-Otero et al., 2023; K. Kim & Kwon, 2023; Nja et al., 2023). Combining traditional methods with advanced technologies and competency frameworks can guide AI implementation in classrooms (Dimitriadou & Lanitis, 2023; Nazaretsky et al., 2022). The importance of teacher expectations regarding AI performance, as well as their knowledge of AI-TPACK, is evident in their willingness to integrate AI into their teaching, as shown in studies on EFL instruction (An et al., 2023).

Real-world examples highlight the impact of innovative AI teaching strategies. For instance, Dai et al. (2024) demonstrate that analogy-based instruction significantly improves student understanding and engagement with AI compared to traditional methods. This finding underscores the need to adapt pedagogical strategies to leverage AI effectively in education. Similarly, Nazaretsky et al. (2022) emphasize the necessity of granting teachers control over AI recommendations and flexibility in using AI tools in diverse educational settings. The adaptability of AI tools to specific school environments is a critical factor for their successful adoption.

In conclusion, professional development, digital literacy, and pedagogical innovation are fundamental to ensuring the effective and ethical integration of AI in education. Providing teachers with agency over AI-driven recommendations and fostering competency-based frameworks will facilitate AI adoption across diverse learning environments. The role of educators remains indispensable in guiding AI integration, ensuring that technology serves as a tool to enhance rather than replace traditional teaching methodologies.

**Table 6. Summary of the main findings of research question Q4**

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 1 | Q4 | Abylkasymova, A. E., Shishov, S. E., Kalney, V. A., & Ryakhimova, E. G. (2022). | Influence of high-tech society on the development of modern educational system. | To explore how high-tech society influences the development of the modern educational system, addressing the formation of a valid educational system, principles of interaction with high-tech education, effective methods and tools, and the role of machines in education. | A need to adapt the education system to the digital era by incorporating technologies such as VR/AR, mobile internet, and digital skills education. |
| 2 | Q2-Q4 | Ayanwale, M. A., Sanusi, I. T., Adelana, O. P., Aruleba, K. D., & Oyelere, S. S. (2022). | Teachers' readiness and intention to teach artificial intelligence in schools. | To explore the factors that influence teachers' intention to teach artificial intelligence (AI) in schools, and to understand teachers' willingness to implement AI in education. | Factors such as AI literacy, confidence in learning, and AI relevance were significant predictors of behavioral intention. Confidence in teaching AI and AI relevance significantly predicted teachers' intention to teach AI. |
| 3 | Q4 | Barakina, E. Y., Popova, A. V, Gorokhova, S. S., & Voskovskaya, A. S. (2021). | Digital Technologies and Artificial Intelligence Technologies in Education. | Explore the use of digital and artificial intelligence (AI) technologies in education, evaluating their benefits, risks, and impact on teaching, learning, and evaluation of students. In addition, it seeks to understand the legal regulations and international experiences in the implementation of these technologies. | Benefits and risks of AI in education.<br>Varied experiences from different countries in the implementation of AI technologies in education.<br>Recommendations for the development of legal regulations in AI in education. |
| 4 | Q2-Q4 | Bozkurt, A. (2023). | Generative Artificial Intelligence (AI) Powered Conversational Educational Agents: The Inevitable Paradigm Shift. | Explore the use and impact of generative artificial intelligence, with a focus on ChatGPT, in education. | Generative artificial intelligence, especially ChatGPT, has significant potential to transform teaching and learning methods. |

| Nº. | Question | Author/year of publication | Title | Objectives of the study | Most relevant results |
|---|---|---|---|---|---|
| 5 | Q4 | Bozkurt, A., Xiao, J., Lambert, S., Pazurek, A., Crompton, H., Koseoglu, S., Farrow, R., Bond, M., Nerantzi, C., Honeychurch, S., Bali, M., M.., Dron, J., Mir, K., Stewart, B., Costello, E., Mason, J., Stracke, C. M., Romero-Hall, E., Koutropoulos, A., ... Jandric, P. (2023) | Speculative Futures on ChatGPT and Generative Artificial Intelligence (AI): A Collective Reflection from the Educational Landscape. | Explore the use and impact of artificial intelligence (AI), specifically ChatGPT, in education. | Widespread use of AI in education for tasks such as research, language learning, and personal support. Concerns about ethics, privacy, and AI bias. The potential of AI to improve or harm education and society. |
| 6 | Q4 | Ipek, Z. H., Gözüm, A. I. C., Papadakis, S., & Kallogiannakis, M. (2023). | Educational Applications of the ChatGPT AI System: Systematic Review Research. | Investigate the impact of ChatGPT on education, exploring both the potential benefits and the ethical challenges and concerns. | ChatGPT has the potential to transform education, offering benefits such as literature review, complex answer generation, personalized learning, and cyberbullying prevention. However, it also raises concerns about academic integrity and ethical issues. |
| 7 | Q2-Q4 | Kim, K., & Kwon, K. (2023). | Exploring the AI competencies of elementary school teachers in South Korea. | To explore the experiences of elementary school teachers in South Korea teaching AI curricula and identify the competencies needed for effective implementation of AI education. | Twenty-two AI competencies were identified for elementary school teachers based on the TPACK framework. Teachers felt most confident in their pedagogical knowledge, followed by technological knowledge and content knowledge. |
| 8 | Q4 | Lo, C. K. (2023) | What Is the Impact of ChatGPT on Education? A Rapid Review of the Literature. | Evaluate the performance of ChatGPT in different academic domains, its potential to improve teaching and learning, and associated problems. | ChatGPT showed outstanding performance in critical thinking and economics but struggled in law, medical education, and mathematics. |
| 9 | Q2-Q4 | Nazaretsky, T., Ariely, M., Cukurova, M., & Alexandron, G. (2022). | Teachers' Trust in AI-Powered Educational Technology and a Professional Development Program to Improve It. | Improve teachers' confidence in AI technology through a professional development program. | Teachers showed an increase in confidence toward AI technology in education, leading to a greater willingness to use AI tools in their classrooms. |

## *Q4. Challenges and Limitations in Integrating AI Into Teaching Practice*

Internal barriers faced by teachers, such as negative perceptions and lack of training and resources, significantly affect the integration of AI-driven education (AIED) (Chalmers et al., 2022; Cheng & Wang, 2023; Yau et al., 2023). Although teachers recognize the importance of AI integration in K-12 education to prepare students for the future and express confidence in their pedagogical knowledge (Yau et al., 2023), they acknowledge significant challenges due to inadequate training, infrastructure, and support for AI curriculum design and implementation (Gentile et al., 2023; K. Kim & Kwon, 2023; Lo, 2023). These barriers hinder the adoption of AI tools in educational settings, limiting their potential benefits.

To address these challenges, professional development programs must focus on AI core competencies, providing teachers with the necessary knowledge and skills to integrate AI effectively (Cheng & Wang, 2023; Chichekian & Benteux, 2022; Gentile et al., 2023; K. Kim & Kwon, 2023; Lim, 2023; López-Martín et al., 2023; Sanusi et al., 2024; Stringer et al., 2022). A holistic approach to teacher training is required, ensuring that educators not only acquire technical knowledge but also develop critical thinking and ethical leadership in AI use (Bozkurt et al., 2023; Gentile et al., 2023). Enhancing teachers' confidence in AI literacy, along with addressing misconceptions, is crucial for fostering AI adoption in classrooms (Nazaretsky et al., 2022).

While AI holds great potential for personalizing learning and improving educational outcomes, studies emphasize that the teacher's role remains central (Barakina et al., 2021; Chalmers et al., 2022; Dimitriadou & Lanitis, 2023). AI is perceived as a tool to enhance education rather than replace educators, underscoring the need for trustworthy and effective AI implementations (Barakina et al., 2021; Leaton, 2020). Ethical considerations surrounding AI integration, including transparency, bias mitigation, and responsible use, must be prioritized (Bozkurt et al., 2023; Dignum, 2021; Pelaez et al., 2022).

Educational institutions must evolve by strengthening their technological infrastructure, providing adequate staff training, and establishing ethical data management practices to overcome emerging challenges (Dimitriadou & Lanitis, 2023). Moving beyond basic digital literacy, AI education should incorporate competencies in stability, IT skills, communication skills, and emotional intelligence (Abylkasymova et al., 2022). This comprehensive approach prepares students for high-tech environments while ensuring responsible AI use.

A key example illustrating these principles is the professional development program for secondary school biology teachers in Israel conducted by Nazaretsky et al. (2022). This initiative included AI literacy sessions, efforts to debunk misconceptions, and strategies for integrating AI recommendations into pedagogy. Teachers used an AI-powered assessment tool, AI-Grader, which led to increased confidence in AI technology and greater willingness to incorporate AI tools into their classrooms. This case highlights the potential of structured professional development programs in addressing barriers to AI adoption in education.

Generative AI applications such as ChatGPT further demonstrate AI's potential to support education. These tools assist in generating course materials, designing assessment tasks, and synthesizing information for students (Lo, 2023). However, concerns remain regarding biased data, outdated knowledge, and ethical challenges such as plagiarism and misinformation (Bozkurt, 2023; Dempere et al., 2023; Gillani et al., 2023; Ipek et al., 2023; Lo, 2023). Addressing these issues requires critical reflection on AI's role in education and the development of frameworks that ensure ethical and responsible use (Bozkurt, 2023; Mallik & Gangopadhyay, 2023; Yan et al., 2024).

Ultimately, overcoming the barriers to AI integration in education demands targeted teacher training, enhanced technological infrastructure, and ethical AI practices. While AI offers promising opportunities to enrich learning, its implementation must prioritize teacher agency, ethical considerations, and the reinforcement of the human element in education.

## DISCUSSION

The integration of AI into K-12 education is reshaping traditional teaching and learning paradigms, offering transformative opportunities while posing complex challenges. Educators worldwide recognize AI's potential to personalize and optimize learning experiences, particularly in underprivileged communities, where disparities in educational resources are most pronounced (S.-W. Kim, 2023; Leaton, 2020; Pua et al., 2021). For instance, S.-W. Kim (2023) conducted a study in underserved South Korean schools, revealing how AI-powered adaptive learning platforms dynamically adjusted content difficulty based on student's performance, leading to notable improvements in literacy and math scores. This capacity for personalization demonstrates AI's ability to bridge educational gaps and provide equitable learning opportunities, which is a priority in global education initiatives.

One of AI's most promising contributions is fostering critical skills essential for 21st-century learners, such as creativity, problem-solving, and critical thinking. In Taiwanese classrooms, S. Chen et al. (2023) investigated the use of humanoid robots to teach computational thinking and programming. The study found that students engaged with these AI-powered tools demonstrated stronger problem-solving abilities and more perseverance when tackling complex tasks than those relying on traditional teaching methods. This aligns with the findings of Chalmers et al. (2022), who emphasize the importance of constructivist, inquiry-based approaches in maximizing AI's educational impact.

Additionally, AI tools are being increasingly utilized to enhance collaboration and teamwork among students. El Hajj and Harb (2023) studied AI-driven collaboration platforms in Lebanon, where AI played a pivotal role in facilitating team-based projects. By assigning roles, monitoring progress, and offering real-time feedback, these tools enhanced students' critical thinking and teamwork skills, demonstrating AI's potential as a "learning partner" rather than a passive tool. Such advancements represent a paradigm shift, positioning AI as an active agent in the learning process that can support instructional scaffolding, encourage collaboration, and deepen engagement.

Case studies from South Korea, Taiwan, Lebanon, and Turkey illustrate the diverse ways in which AI can transform education when implemented thoughtfully and strategically. For example, S.-W. Kim's (2023) work with underprivileged schools underscores AI's potential to level the playing field for underserved students. Similarly, S. Chen et al. (2023) and El Hajj and Harb (2023) demonstrate how AI can foster essential 21st-century skills, from computational thinking to teamwork. These real-world applications reveal that AI's effectiveness is contingent on context-specific strategies that consider the unique challenges and opportunities of each educational setting.

Despite these advancements, educators face persistent barriers to the successful integration of AI. Among these are insufficient training, limited access to resources, and ethical concerns such as data privacy, academic integrity, and biases embedded in AI algorithms (Bozkurt et al., 2023; Grassini, 2023). For example, Ipek et al. (2023) examined the ethical implications of AI integration in Turkish schools, highlighting the challenges of protecting student data while ensuring transparency and fairness. Their recommendations – legal frameworks, teacher training programs, and the development of ethical guidelines – illustrate the critical steps needed to address these issues. Similarly, educators in other contexts report apprehensions regarding their preparedness to navigate the complexities of AI tools effectively (Dignum, 2021; Molenaar, 2022).

Integrating AI requires addressing critical gaps in digital literacy and teacher preparedness effectively. Many educators express the need for comprehensive training programs that focus on technical skills and the interpersonal competencies necessary for success in technology-driven environments

(Abylkasymova et al., 2022; Bozkurt et al., 2023). These programs should prioritize self-efficacy and equip educators with tools to incorporate AI into their teaching practices, particularly in resource-constrained settings (Chichekian & Benteux, 2022; Karalekas et al., 2023). For example, Abylkasymova et al. (2022) advocate for professional development programs that combine hands-on experimentation with theoretical knowledge, enabling educators to explore AI's potential while building confidence in its application.

Beyond technical implementation, ethical considerations remain central to discussions about AI in education. Generative AI tools, such as ChatGPT, exemplify both the opportunities and challenges of integrating these technologies. While they offer innovative applications, such as personalized feedback and content generation, they also raise concerns about data security, plagiarism, and biases that could perpetuate systemic inequities (Lo, 2023; Yan et al., 2024). To mitigate these risks, a human-centered approach to AI development is a necessary one that emphasizes transparency, fairness, and accountability. Ipek et al. (2023) underline the importance of establishing ethical frameworks that balance technological innovation with respect for human values.

Another critical factor in AI integration is the design of curriculum and pedagogy that align with the demands of an AI-driven world. The incorporation of computational thinking, programming, and coding into digital curricula has been shown to enhance students' creativity and AI literacy (Bozkurt, 2023; Dimitriadou & Lanitis, 2023). Moreover, project-based learning approaches that utilize AI tools can simultaneously promote problem-solving skills and ethical awareness, fostering a deeper understanding of the social implications of these technologies (Dai et al., 2024; Lim, 2023).

In conclusion, the integration of AI into education represents a powerful tool for addressing persistent inequities, fostering critical skills, and transforming learning experiences. However, its successful adoption hinges on a collective effort among educators, policymakers, and technologists to design ethical, user-friendly systems and targeted training programs. A holistic framework that balances technological innovation with human-centric values is essential to harnessing AI's full potential. As real-world case studies demonstrate, when implemented responsibly, AI has the power to redefine education, preparing students to thrive in an increasingly AI-driven future.

Despite these promising prospects, the present study highlights several limitations that reveal significant gaps in the analysis of AI implementation in education. One of the main gaps is the lack of empirical studies that assess how AI integration impacts school contexts with limited resources, where technological infrastructure and access to advanced tools are often inadequate. Moreover, there has been insufficient investigation into how different AI tools, such as virtual tutors or learning analytics systems, influence student engagement and participation in diverse environments. These shortcomings, coupled with the inadequate preparation of educators in digital and AI-specific competencies (Abylkasymova et al., 2022; Bozkurt et al., 2023; Casal-Otero et al., 2023; Gentile et al., 2023; J. Kim et al., 2022; K. Kim & Kwon, 2023; Nja et al., 2023), as well as ethical concerns related to privacy and algorithmic biases (Bozkurt et al., 2023; Dimitriadou & Lanitis, 2023; Ipek et al., 2023; Lo, 2023; Yan et al., 2024), hinder the effective adoption of these technologies in education.

## LIMITATIONS, RECOMMENDATIONS, AND IMPLICATIONS

The scope and methodology of any research inherently shape its findings and implications, yet certain limitations can constrain the generalizability and depth of the results.

In this study, several constraints were identified, delineating the contextual boundaries within which the analysis was conducted. While these limitations are critical to acknowledge, they also underscore opportunities for further exploration and refinement in future research. First, the study exclusively focused on articles written in English, potentially excluding relevant studies published in other languages. Second, the selected studies were limited to applying open-ended inquiry methodologies within social science qualifications and school-based contexts, thereby neglecting other academic disciplines and educational settings. Third, the analysis primarily relied on publications from research journals, which may introduce a publication bias by excluding insights from other sources, such as conference proceedings or grey literature. Finally, the articles reviewed were predominantly sourced from academic databases like WOS, Scopus, and ERIC, potentially overlooking valuable studies available in non-indexed or alternative repositories.

The implementation of artificial intelligence (AI) in education faces several limitations that must be addressed to ensure effective and ethical integration. First, one of the main barriers is the lack of preparedness and readiness of teachers to use these technologies efficiently. Digital literacy and educator self-efficacy are areas that require immediate attention. AI, moreover, is not completely transparent to educational stakeholders and does not always adequately consider privacy and equality, which can lead to distrust and resistance among educators and students (Yan et al., 2024). There are also ethical and legal concerns in the adoption of AI technologies in education that need to be addressed, such as transparency, privacy, and bias in AI algorithms (Mallik & Gangopadhyay, 2023). Another significant limitation is the lack of adequate training for educators. Teachers who have not received specific training in AI may feel insecure and ineffective in integrating this technology into the classroom (Casal-Otero et al., 2023; Chalmers et al., 2022). This lack of confidence may hinder the adoption and effective use of AI tools in education. Also, insufficient technological infrastructure represents a barrier, as many educational institutions lack the necessary resources to implement these technologies effectively (Abylkasymova et al., 2022).

To overcome these limitations, several recommendations are proposed. First, it is essential to develop continuing education programs for educators that focus on concrete pedagogical tasks and confidence building in the use of AI (An et al., 2023; Casal-Otero et al., 2023). These programs should provide procedural knowledge about AI and address misconceptions to increase teachers' confidence in this technology (Bozkurt, 2023). Training should go beyond basic digital literacy and include competencies in stability, IT skills, communication skills, and emotional intelligence (Abylkasymova et al., 2022). In addition, human agency should be emphasized in AI recommendations by developing regulations and practices that respect pedagogical rights and ensure fair and transparent use of AI in educational settings. It must be ensured that educators maintain control over pedagogical decisions (El Hajj & Harb, 2023; Leaton, 2020; Nazaretsky et al., 2022). Humanizing online education and promoting effective interaction between AI tools and learners is essential to ensure a positive learning experience (Pelaez et al., 2022). Finally, it is critical to address ethical and legal concerns by implementing clear and transparent policies that protect privacy and promote equality (Dempere et al., 2023; Gillani et al., 2023). Creating a robust regulatory framework can help mitigate the risks associated with the use of AI in education.

The integration of AI in education has significant implications for the future of learning and teaching. To maximize the benefits of this technology, it is essential to prepare both educators and students for an AI-enabled educational environment (Sanusi et al., 2024). AI literacy, confidence in learning, and the perceived relevance of AI are critical predictors of teacher behavioral intentions. Therefore, training programs should focus on these aspects to foster effective adoption of AI in educational settings (Casal-Otero et al., 2023; Chalmers et al., 2022; Lim, 2023). In addition, AI offers the possibility of promoting more personalized and collaborative learning, using technologies such as robot tutors and virtual reality, which can significantly enrich the educational experience (Benvenuti et al., 2023). However, it is essential to maintain a balance between the implementation of these advanced technologies and traditional teaching methods to ensure quality learning outcomes (Bozkurt, 2023).

A major limitation identified in this review is the lack of intervention studies evaluating the implementation of artificial intelligence (AI) in the classroom. The absence of empirical research analyzing the outcomes of such interventions hinders a complete understanding of the real impact of AI in education. Therefore, it underscores the need for future intervention studies that address this gap, thus allowing them to optimize its application and maximize its benefits in the educational setting. In this way, it will be possible to more precisely identify areas for improvement and develop more effective strategies that maximize the benefits of AI in education.

Key areas for future research are identified to address these deficiencies. It is essential to expand the analysis to include multicultural and multilingual perspectives, explore AI applications across various disciplines and educational levels, and encourage interdisciplinary research that considers ethical, social, and pedagogical aspects. Conducting long-term intervention studies in real-world contexts will allow for the evaluation of AI's impact on learning, while the development of advanced teacher training programs will help increase confidence and effectiveness in using these technologies. Additionally, it is crucial to investigate models of sustainable technological infrastructure to ensure the accessibility of AI in resource-limited communities and to design robust ethical and regulatory frameworks that promote the responsible use of technology. These actions will be fundamental to optimizing the impact of AI in education and ensuring its equitable and ethical integration.

## CONCLUSIONS

The integration of AI into K-12 and primary education has emerged as a transformative trend, promising to redefine teaching and learning processes. This systematic literature review, encompassing studies from 2014 to 2024, has highlighted both the potential and the challenges associated with AI adoption in education. On the one hand, AI offers immense opportunities to personalize learning, foster 21st-century skills such as computational thinking, creativity, and teamwork, and prepare students for an increasingly digitized world. On the other hand, this integration raises pressing concerns that necessitate a multifaceted and ethically grounded approach to ensure its effectiveness and fairness.

One of the key findings of the reviewed studies is the critical role of teacher training in successfully integrating AI into the classroom. Advanced training programs that enhance educators' confidence and competency in AI technology are essential. Such programs must focus on both theoretical and practical aspects, equipping teachers with the skills to effectively incorporate AI tools into their pedagogical practices. Additionally, ongoing support is crucial to help educators design and implement AI-enhanced curricula that are both innovative and pedagogically sound.

From a policy perspective, there is a pressing need to develop curricular frameworks that integrate computational thinking, programming, and project-based learning. These approaches not only improve students' AI literacy but also enable them to critically engage with the social and ethical implications of AI technologies. Simultaneously, sustainable technological infrastructure must be established to ensure equitable access to AI tools, particularly in resource-constrained communities. Without addressing these systemic disparities, the potential of AI to democratize education and bridge learning gaps cannot be fully realized.

Ethical considerations are paramount in the adoption of AI in education. Issues such as data privacy, algorithmic biases, and academic integrity must be addressed through robust regulatory frameworks. The implementation of transparent and accountable AI systems will not only mitigate ethical risks but also foster trust among stakeholders, including students, educators, and policymakers. These frameworks should be designed to promote human agency, ensuring that technology complements rather than replaces the vital role of educators.

Another significant insight from the analysis is the need to expand research on AI integration in education to include multicultural and multilingual perspectives. Current studies predominantly focus on English-language contexts, overlooking the diverse linguistic and cultural environments in which AI can be applied. Furthermore, interdisciplinary research that examines AI applications across various disciplines and educational levels is crucial to understanding its broader implications. Long-term intervention studies in real-world settings will also provide valuable insights into the sustained impact of AI on learning outcomes and student engagement.

The effectiveness of AI in education is deeply tied to its context-specific application. Strategies that consider the unique challenges and opportunities of different educational environments are critical. By tailoring AI tools to the needs of specific contexts, whether rural schools with limited resources or urban classrooms with advanced technological access, the full potential of AI can be harnessed to enhance teaching and learning.

In conclusion, the successful integration of AI into education requires a collaborative effort among educators, policymakers, and technologists. Ethical, user-friendly systems must be designed alongside targeted teacher training programs and inclusive educational policies. A holistic approach that balances technological innovation with human-centric values is essential to optimizing the impact of AI in education. This approach will not only address persistent challenges but also ensure the equitable and ethical integration of AI, preparing students to thrive in a rapidly evolving technological landscape. By embracing these recommendations, the transformative potential of AI in shaping the future of education can be fully realized.

## REFERENCES

Abylkasymova, A. E., Shishov, S. E., Kalney, V. A., & Ryakhimova, E. G. (2022). Influence of high-tech society on the development of modern educational system. *Journal of Higher Education Theory and Practice, 22*(5), 201-206. https://doi.org/10.33423/jhetp.v22i5.5214

An, X., Chai, C. S., Li, Y., Zhou, Y., Shen, X., Zheng, C., & Chen, M. (2023). Modeling English teachers' behavioral intention to use artificial intelligence in middle schools. *Education and Information Technologies, 28*(5), 5187-5208. https://doi.org/10.1007/s10639-022-11286-z

Ayanwale, M. A., Sanusi, I. T., Adelana, O. P., Aruleba, K. D., & Oyelere, S. S. (2022). Teachers' readiness and intention to teach artificial intelligence in schools. *Computers and Education: Artificial Intelligence, 3*, 100099. https://doi.org/10.1016/j.caeai.2022.100099

Barakina, E. Y., Popova, A. V., Gorokhova, S. S., & Voskovskaya, A. S. (2021). Digital technologies and artificial intelligence technologies in education. *European Journal of Contemporary Education, 10*(2), 285-296. https://doi.org/10.13187/ejced.2021.2.285

Benvenuti, M., Cangelosi, A., Weinberger, A., Mazzoni, E., Benassi, M., Barbaresi, M., & Orsoni, M. (2023). Artificial intelligence and human behavioral development: A perspective on new skills and competencies acquisition for the educational context. *Computers in Human Behavior, 148*, 107903. https://doi.org/10.1016/j.chb.2023.107903

Bozkurt, A. (2023). Generative artificial intelligence (AI) powered conversational educational agents: The inevitable paradigm shift. *Asian Journal of Distance Education, 18*(1), 198-204. https://doi.org/10.5281/zenodo.7716416

Bozkurt, A., Xiao, J., Lambert, S., Pazurek, A., Crompton, H., Koseoglu, S., Farrow, R., Bond, M., Nerantzi, C., Honeychurch, S., Bali, M., Dron, J., Mir, K., Stewart, B., Costello, E., Mason, J., Stracke, C. M., Romero-Hall, E., Koutropoulos, A., … Jandric, P. (2023). Speculative futures on ChatGPT and generative artificial intelligence (AI): A collective reflection from the educational landscape. *Asian Journal of Distance Education, 18*(1), 53-130. https://doi.org/10.5281/zenodo.7636568

Casal-Otero, L., Catala, A., Fernandez-Morante, C., Taboada, M., Cebreiro, B., & Barro, S. (2023). AI literacy in K-12: A systematic literature review. *International Journal of Stem Education, 10*, Article 29. https://doi.org/10.1186/s40594-023-00418-7

Chalmers, C., Keane, T., Boden, M., & Williams, M. (2022). Humanoid robots go to school. *Education and Information Technologies, 27*(6), 7563-7581. https://doi.org/10.1007/s10639-022-10913-z

Chen, S., Qiu, S., Li, H., Zhang, J., Wu, X., Zeng, W., & Huang, F. (2023). An integrated model for predicting pupils' acceptance of artificially intelligent robots as teachers. *Education and Information Technologies, 28*(9), 11631-11654. https://doi.org/10.1007/s10639-023-11601-2

Chen, X., Zou, D., Xie, H., Cheng, G., & Liu, C. (2022). Two decades of artificial intelligence in education: Contributors, collaborations, research topics, challenges, and future directions. *Educational Technology & Society, 25*(1), 28-47. https://www.jstor.org/stable/48647028

Chen, Y., & Zou, Y. (2024). Enhancing education quality: Exploring teachers' attitudes and intentions towards intelligent MR devices. *European Journal of Education*, *59*(4), e12692. https://doi.org/10.1111/ejed.12692

Cheng, E. C. K., & Wang, T. (2023). Leading digital transformation and eliminating barriers for teachers to incorporate artificial intelligence in basic education in Hong Kong. *Computers and Education: Artificial Intelligence, 5*, 100171. https://doi.org/10.1016/j.caeai.2023.100171

Chichekian, T., & Benteux, B. (2022). The potential of learning with (and not from) artificial intelligence in education. *Frontiers in Artificial Intelligence, 5,* 903051. https://doi.org/10.3389/frai.2022.903051

Consoli, T., Désiron, J., & Cattaneo, A. (2023). What is "technology integration" and how is it measured in K-12 education? A systematic review of survey instruments from 2010 to 2021. *Computers & Education, 197*, 104742. https://doi.org/10.1016/j.compedu.2023.104742

Dai, Y., Lin, Z., Liu, A., Dai, D., & Wang, W. (2024). Effect of an analogy-based approach of artificial intelligence pedagogy in upper primary schools. *Journal of Educational Computing Research, 61*(8), 159-186. https://doi.org/10.1177/07356331231201342

Dempere, J., Modugu, K., Hesham, A., & Ramasamy, L. K. (2023). The impact of ChatGPT on higher education. *Frontiers in Education, 8*, 1206936. https://doi.org/10.3389/feduc.2023.1206936

Dignum, V. (2021). The role and challenges of education for responsible Al. *London Review of Education, 19*(1), 1-11. https://doi.org/10.14324/LRE.19.1.01

Dimitriadou, E., & Lanitis, A. (2023). A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in smart classrooms. *Smart Learning Environments, 10*, Article 12. https://doi.org/10.1186/s40561-023-00231-3

Dong, W., Li, Y. J., Sun, L. H., & Liu, Y. R. (2023). Developing pre-service teachers' computational thinking: A systematic literature review. *International Journal of Technology and Design Education 34*, 191-227. https://doi.org/10.1007/s10798-023-09811-3

Elayyan, S. (2021). The future of education according to the fourth industrial revolution. *Journal of Educational Technology and Online Learning, 4*(1), 23-30. https://doi.org/10.31681/jetol.737193

El Hajj, M., & Harb, H. (2023). Rethinking education: An in-depth examination of modern technologies and pedagogic recommendations. *IAFOR Journal of Education, 11*(2), 97-113. https://doi.org/10.22492/ije.11.2.05

García-Peñalvo, F. J., Llorens-Largo, F., & Vidal, J. (2024). La nueva realidad de la educación ante los avances de la inteligencia artificial generativa. *RIED-Revista Iberoamericana de Educación a Distancia, 27*(1). https://doi.org/10.5944/ried.27.1

Gentile, M., Città, G., Perna, S., & Allegra, M. (2023). Do we still need teachers? Navigating the paradigm shift of the teacher's role in the AI era. *Frontiers in Education, 8*, 1161777. https://doi.org/10.3389/feduc.2023.1161777

Gerard, L., Matuk, C., McElhaney, K., & Linn, M. C. (2015). Automated, adaptive guidance for K-12 education. *Educational Research Review, 15*, 41-58. https://doi.org/10.1016/j.edurev.2015.04.001

Gillani, N., Eynon, R., Chiabaut, C., & Finkel, K. (2023). Unpacking the "Black Box" of AI in education. *Educational Technology & Society, 26*(1), 99-111. https://doi.org/10.30191/ETS.202301_26(1).0008

Grassini, S. (2023). Shaping the future of education: Exploring the potential and consequences of AI and ChatGPT in educational settings. *Education Sciences, 13*(7), 692. https://doi.org/10.3390/educsci13070692

Han, A., Zhou, X., Cai, Z., & Han, S. (2024). Teachers, parents, and students' perspectives on integrating generative AI into elementary literacy education. *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Article 678). Association for Computing Machinery. https://doi.org/10.1145/3613904.3642438

Ipek, Z. H., Gözüm, A. I. C., Papadakis, S., & Kallogiannakis, M. (2023). Educational applications of the ChatGPT AI system: A systematic review research. *Educational Process: International Journal, 12*(3), 26-55. https://doi.org/10.22521/edupij.2023.123.2

Karalekas, G., Vologiannidis, S., & Kalomiros, J. (2023). Teaching machine learning in K-12 using robotics. *Education Sciences, 13*(1), 67. https://doi.org/10.3390/educsci13010067

Khan, K. S., Bueno Cavanillas, A., & Zamora, J. (2022). Revisiones sistemáticas en cinco pasos: I. Cómo formular una pregunta para la que se pueda obtener una respuesta válida [Systematic reviews in five steps: I. Framing questions to obtain valid answers]. *Medicina de Familia – Semergen, 48*(5), 356-361. https://doi.org/10.1016/j.semerg.2021.12.005

Kim, J., Lee, H., & Cho, Y. H. (2022). Learning design to support student-AI collaboration: Perspectives of leading teachers for AI in education. *Education and Information Technologies, 27*(5), 6069-6104. https://doi.org/10.1007/s10639-021-10831-6

Kim, K., & Kwon, K. (2023). Exploring the AI competencies of elementary school teachers in South Korea. *Computers and Education: Artificial Intelligence, 4,* 100137. https://doi.org/10.1016/j.caeai.2023.100137

Kim, S.-W. (2023). Change in attitude toward artificial intelligence through experiential learning in artificial intelligence education. *International Journal on Advanced Science, Engineering and Information Technology, 13*(5), 1953-1959. https://doi.org/10.18517/ijaseit.13.5.19039

Leaton, S. (2020). Artificial intelligence in schools: Towards a democratic future. *London Review of Education, 18*(2), 163-177. https://doi.org/10.14324/LRE.18.2.02

Lee, S., Chang, K., & Lee, K. (2023). A classroom-based study on the application of artificial intelligence translator: The use and perception of AI by low-achieving primary school English learners. *The Korea Association of Primary English Education*. https://doi.org/10.25231/pee.2023.29.1.31

Lim, E. M. (2023). The effects of pre-service early childhood teachers' digital literacy and self-efficacy on their perception of AI education for young children. *Education and Information Technologies, 28*(10), 12969-12995. https://doi.org/10.1007/s10639-023-11724-6

Lo, C. K. (2023). What is the impact of ChatGPT on education? A rapid review of the literature. *Education Sciences, 13*(4), 410. https://doi.org/10.3390/educsci13040410

López-Martín, E., Gutiérrez-de-Rozas, B., González-Benito, A. M., & Expósito-Casas, E. (2023). Why do teachers matter? A meta-analytic review of how teacher characteristics and competencies affect students' academic achievement. *International Journal of Educational Research, 120*, 102199. https://doi.org/10.1016/j.ijer.2023.102199

Mallik, S., & Gangopadhyay, A. (2023). Proactive and reactive engagement of artificial intelligence methods for education: A review. *Frontiers in Artificial Intelligence, 6*, 1151391. https://doi.org/10.3389/frai.2023.1151391

Molenaar, I. (2022). Towards hybrid human-AI learning technologies. *European Journal of Education, 57*(4), 632-645. https://doi.org/10.1111/ejed.12527

Nazaretsky, T., Ariely, M., Cukurova, M., & Alexandron, G. (2022). Teachers' trust in AI-powered educational technology and a professional development program to improve it. *British Journal of Educational Technology, 53*(4), 914-931. https://doi.org/10.1111/bjet.13232

Ng, D. T. K., Lee, M., Tan, R. J. Y., Hu, X., Downie, J. S., & Chu, S. K. W. (2023). A review of AI teaching and learning from 2000 to 2020. *Education and Information Technologies, 28*, 8445-8501. https://doi.org/10.1007/s10639-022-11491-w

Nja, C. O., Idiege, K. J., Uwe, U. E., Meremikwu, A. N., Ekon, E. E., Erim, C. M., Ukah, J. U., Eyo, E. O., Anari, M. I., & Cornelius-Ukpepi, B. U. (2023). Adoption of artificial intelligence in science teaching: from the vantage point of the African science teachers. *Smart Learning Environments, 10*, Article 42. https://doi.org/10.1186/s40561-023-00261-x

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). Declaración PRISMA 2020: una guía actualizada para la publicación de revisiones sistemáticas [The PRISMA 2020 statement: An updated guideline for reporting systematic reviews]. *Revista Española de Cardiología, 74*(9), 790-799. https://doi.org/10.1016/j.recesp.2021.06.016

Pelaez, A., Jacobson, A., Trias, K., & Winston, E. (2022). The Turing teacher: Identifying core attributes for AI learning in K-12. *Frontiers in Artificial Intelligence, 5*, 1031450. https://doi.org/10.3389/frai.2022.1031450

Pradana, M., Elisa, H. P., & Syarifuddin, S. (2023). Discussing ChatGPT in education: A literature review and bibliometric analysis. *Cogent Education, 10*(2), Article 2243134. https://doi.org/10.1080/2331186X.2023.2243134

Pua, S., Ahmad, N. A., & Khambari, M. N. M. (2021). Identification and analysis of core topics in educational artificial intelligence research: A bibliometric analysis. *Cypriot Journal of Educational Sciences*, *16*(3), 995-1009. https://doi.org/10.18844/cjes.v16i3.5782

Rienties, B., Køhler Simonsen, H., & Herodotou, C. (2020). Defining the boundaries between artificial intelligence in education, computer-supported collaborative learning, educational data mining, and learning analytics: A need for coherence. *Frontiers in Education, 5*, 128. https://doi.org/10.3389/feduc.2020.00128

Sanusi, I. T., Ayanwale, M. A., & Chiu, T. K. F. (2024). Investigating the moderating effects of social good and confidence on teachers' intention to prepare school students for artificial intelligence education. *Education and Information Technologies, 29*(1), 273-295. https://doi.org/10.1007/s10639-023-12250-1

Sharifuddin, N. S., & Hashim, H. (2024). Benefits and challenges in implementing artificial intelligence in education (AIED) in ESL classroom: A systematic review (2019-2022). *International Journal of Academic Research in Business and Social Sciences, 14*(1), 146-164. https://doi.org/10.6007/IJARBSS/v14-i1/20422

Stringer, L. R., Lee, K. M., Sturm, S., & Giacaman, N. (2022). A systematic review of primary school teachers' experiences with digital technologies curricula. *Education and Information Technologies, 27*(9), 12585-12607. https://doi.org/10.1007/s10639-022-11127-z

Yan, L., Sha, L., Zhao, L., Li, Y., Martinez-Maldonado, R., Chen, G., Li, X., Jin, Y., & Gašević, D. (2024). Practical and ethical challenges of large language models in education: A systematic scoping review. *British Journal of Educational Technology, 55*(1), 90-112. https://doi.org/10.1111/bjet.13370

Yau, K. W., Chai, C. S., Chiu, T. K. F., Meng, H., King, I., & Yam, Y. (2023). A phenomenographic approach on teacher conceptions of teaching artificial intelligence (AI) in K-12 schools. *Education and Information Technologies, 28*, 1041-1064. https://doi.org/10.1007/s10639-022-11161-x

Zhang, Y. (2024). Analysis of the application of artificial intelligence in information courses in primary and secondary schools. *Lecture Notes in Education Psychology and Public Media, 59*, 241-250. https://doi.org/10.54254/2753-7048/59/20241783

# APPENDIX A

**Summary of the main findings of research question Q1**

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 1 | Q1-Q2 | An, X., Chai, C. S., Li, Y., Zhou, Y., Shen, X., Zheng, C., & Chen, M. (2023). | Education and Information Technologies, 28(5), 5187-5208. | Modeling English teachers' behavioral intention to use artificial intelligence in middle schools. | To investigate the perceptions, knowledge, and intended use of AI by English as a foreign language (EFL) teachers in secondary education. | Use of surveys and data analysis based on the Unified Theory of Acceptance and Use of Technology (UTAUT) and Technological Pedagogical Content Knowledge (TPACK). | EFL teachers have positive perceptions toward the use of AI in teaching, with Performance Expectancy and knowledge of AI-TPACK as influential factors in their intention to use it. | Performance Expectations and knowledge of AI-TPACK are determinants of teachers' intention to use AI. Effort Expectation does not directly predict intention to use. |
| | | | | | To examine factors influencing EFL teachers' intention to use AI in education. | Development and validation of a scale to measure teachers' perceptions of TPACK and UTAUT concerning AI, through surveys and data analysis. | Teachers' knowledge of AI-TPACK significantly predicts their intention to use it. Other factors such as technological knowledge of the AI language and Enabling Conditions are also influential. | Specific knowledge about AI and pedagogical integration is key to teachers' intention to use it. |
| 2 | Q1-Q2 | Benvenuti, M., Cangelosi, A., Weinberger, A., Mazzoni, E., Benassi, M., Barbaresi, M., & Orsoni, M. (2023). | Computers in Human Behavior, 148. | Artificial intelligence and human behavioral development: A perspective on new skills and competencies acquisition for the educational context. | Explore how digitization and artificial intelligence (AI) can promote 21st-century skills such as creativity, critical thinking, problem-solving, and computational thinking in educational contexts. | Literature review using the PRISMA protocol, focusing on articles related to education, IA, and critical thinking. | Integrating computational thinking, programming, and coding into school curricula is essential. Creativity can enhance computational thinking, and AI can foster creativity. Critical thinking is crucial for problem-solving and can be enhanced through computational thinking and programming with the help of AI. | IA can be a valuable tool for improving skills such as creativity, critical thinking, and problem-solving. |
| | | | | | | | | The interrelationship between creativity, computational thinking, and critical thinking is fundamental to effective learning. |
| | | | | | | | | Technology, including AI, robot tutors, and virtual reality, can promote more personalized and collaborative learning. |
| 3 | Q1-Q2 | Casal-Otero, L., Catala, A., Fer- | *International Journal of Stem Education*, *10*(1). | AI literacy in K-12: A systematic literature review. | Understand how artificial intelligence (AI) is being integrated into K- | Systematic literature review using Scopus, ana- | A growing interest in IA education in K-12 schools was identified, | Need for a competency framework to guide IA literacy proposals. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| | | nandez-Morante, C., Taboada, M., Cebreiro, B., & Barro, S. (2023). | | | 12 education globally, identifying learning experience approaches and theoretical perspectives. | lyzing 179 articles focused on learning experiences and theoretical perspectives. | with a variety of approaches to teaching IA concepts to students. | Importance of teacher training and systemic approaches to IA education.<br>IA literacy should enhance learning in core subjects and promote interdisciplinary and critical approaches. |
| 4 | Q1 | Chalmers, C., Keane, T., Boden, M., & Williams, M. (2022). | *Education and Information Technologies, 27*(6), 7563-7581. | Humanoid robots go to school. | To explore teachers' perceptions of the use of humanoid robots in the classroom, and how they can enhance curriculum and student engagement. | Questionnaires, reflective diaries, and semi-structured interviews were used with 29 teachers from 10 schools. | Teachers reported benefits in the use of robots for student engagement and learning, highlighting innovation, creativity, and computational thinking. | Humanoid robots have a positive impact on student learning, increasing engagement and the development of transferable skills.<br>Teachers adopted a social constructivist learning approach, using robots to develop 21st-century skills and perseverance. |
| 5 | Q1 | Chen, S., Qiu, S., Li, H., Zhang, J., Wu, X., Zeng, W., & Huang, F. (2023). | *Education and Information Technologies, 28*(9), 11631-11654. | An Integrated Model for Predicting Pupils' Acceptance of Artificially Intelligent Robots as Teachers. | To investigate the acceptance of an AI teacher among primary school students in China, identify factors that influence this acceptance, and explore the role of technology in education. | An AI teacher was developed, and its acceptance was evaluated through questionnaires and interaction in elementary schools. An extended Technology Acceptance Model (TAM) was used to analyze the acceptance factors. | Student acceptance of the AI teacher was moderate. The factors most influencing acceptance were perceived usefulness, ease of use, and task characteristics. Previous experience with IA teachers also affects acceptance. | Perceived usefulness is the most critical factor affecting IA teacher acceptance.<br>Ease of use and task characteristics are also important but to a lesser extent.<br>Previous experience with similar technologies may influence acceptance. |
| 6 | Q1 | Gerard, L., Matuk, C., McElhaney, K., & Linn, M. C. (2015). | *Educational Research Review, 15*, 41-58. | Automated, adaptive guidance for K-12 education. | Investigate the effectiveness of automated, adaptive guidance in K-12 education compared to traditional teacher-directed instruction. To explore specific features of automated guidance | Meta-analysis of 41 studies and 57 independent effect sizes on automated guidance in K-12 education. Classification of studies into automated adaptive | Automated, adaptive guidance is generally as effective or more effective than traditional instruction in improving student learning outcomes. Enhanced guid- | Automated guidance is particularly beneficial for students with low to medium prior knowledge.<br>Enhanced orientation favors conceptual learning and the development of self-monitoring strategies. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| | | | | | that enhance student learning. | guidance vs. typical instruction. | ance (with detailed feedback or motivational scaffolding) is more effective than simpler forms of guidance. | Features such as scaffolding of generative tasks and the use of generative tasks for assessment lead to better learning outcomes. |
| 7 | Q1-Q3 | El Hajj, M., & Harb, H. (2023). | *IAFOR Journal of Education*, *11*(2), 97-113. | Rethinking Education: An In-Depth Examination of Modern Technologies and Pedagogic Recommendations. | Explore the integration of technology in education through the Technological Pedagogical Content Knowledge (TPCK) framework, emphasizing student-centered learning. | Literature review on technology integration in education and analysis of teaching strategies using technology. | Technology-based education improves student learning by integrating technological tools into the teaching and learning process. | The critical importance of teachers in guiding and supporting student growth and success in technology-based learning environments. There is a need for ongoing professional development and training programs for teachers to effectively integrate technology into the classroom. |
| | | | | | Identify technological tools that facilitate interactive and engaging teaching strategies. | List of technological tools used to facilitate various teaching strategies. | Technology tools such as Tricider, AnswerGarden, and MindMeister, among others, can be used to facilitate teaching strategies such as flipped classrooms, inquiry-based learning, and peer feedback. | These tools help create interactive and engaging learning experiences for students. They promote collaboration, critical thinking, and self-regulated learning skills. |
| 8 | Q1-Q2 | Kim, J., Lee, H., & Cho, Y. H. (2022). | *Education and Information Technologies*, *27*(5), 6069-6104. | Learning Design to Support Student-AI Collaboration: Perspectives of Leading Teachers for AI in Education. | Explore the integration of Artificial Intelligence (AI) in education, focusing on student-AI collaboration, and how this can improve learning in K-12 schools. | It is not explicitly described in the excerpts provided but is inferred to be based on the exploration of teacher perspectives on student-AI collaboration. | Teachers view student-AI collaboration as a tool for achieving optimal learning objectives, emphasizing the importance of knowledge construction, interdisciplinary learning, authentic problem-solving, and creative assignments. | The importance of student-AI collaboration in learning. |
| | | | | | | | | Need for systematic AIED policies to improve AI applications in education. |
| | | | | | | | | AI as a "learning companion" that provides instructional scaffolding. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 9 | Q1-Q2 | Lim, E. M. (2023). | Education and Information Technologies, 28(10), 12969-12995. | The Effects of Pre-Service Early Childhood Teachers' Digital Literacy and Self-Efficacy on Their Perception of AI Education for Young Children. | To examine the relationship between digital literacy, self-efficacy, and perceptions of AI (Artificial Intelligence) education for young children among prospective early childhood education teachers. | Surveys were conducted with 212 prospective early childhood education teachers, using descriptive statistics, correlation analysis, and hierarchical multiple regression analysis. | The means of digital literacy, self-efficacy, and perception of AI education were 3.43, 3.31, and 3.36 respectively, indicating a positive relationship between these variables. Self-efficacy measured the relationship between digital literacy and perception of AI education. | Digital literacy and self-efficacy have a positive impact on the perception of AI education for young children. Self-efficacy plays a mediating role between digital literacy and perception of AI education. |
| 10 | Q1 | Sanusi, I. T., Ayanwale, M. A., & Chiu, T. K. F. (2024). | Education and Information Technologies, 29(1), 273-295. | Investigating the Moderating Effects of Social Good and Confidence on Teachers' Intention to Prepare School Students for Artificial Intelligence Education. | To examine factors influencing teachers' intention to teach artificial intelligence (AI) in schools, including anxiety toward AI, perceived usefulness, attitude toward AI, AI relevance, AI readiness, and behavioral intention. In addition, to investigate the moderating effects of AI for social good and confidence in teaching AI. | Data were collected from 320 in-service teachers in Nigeria using a variance-based structural equation modeling approach. | AI relevance was the most significant predictor of intention to teach AI. Perception of AI for social good and confidence in teaching AI had significant impacts on the intention to teach AI. | Teachers generally have positive attitudes toward the use of AI and confidence in teaching it but may have some anxiety about the future impact of AI.<br>The relevance of AI and the perception of AI for social good are crucial factors influencing teachers' intention to teach AI.<br>Confidence in AI teaching moderates some relationships in the model. |

# APPENDIX B

**Summary of the main findings of research question Q2**

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 1 | Q1-Q2 | An, X., Chai, C. S., Li, Y., Zhou, Y., Shen, X., Zheng, C., & Chen, M. (2023). | Education and Information Technologies, 28(5), 5187-5208. | Modeling English Teachers' Behavioral Intention to Use Artificial Intelligence in Middle Schools. | To investigate the perceptions, knowledge, and intended use of AI by English as a foreign language (EFL) teachers in secondary education. | Use of surveys and data analysis based on the Unified Theory of Acceptance and Use of Technology (UTAUT) and Technological Pedagogical Content Knowledge (TPACK). | EFL teachers have positive perceptions toward the use of AI in teaching, with Performance Expectancy and knowledge of AI-TPACK as influential factors in their intention to use it. | Performance Expectations and knowledge of AI-TPACK are determinants of teachers' intention to use AI. Effort Expectation does not directly predict intention to use. |
| | | | | | To examine factors influencing EFL teachers' intention to use AI in education. | Development and validation of a scale to measure teachers' perceptions of TPACK and UTAUT about AI through surveys and data analysis. | Teachers' knowledge of AI-TPACK significantly predicts their intention to use it. Other factors such as technological knowledge of the AI language and Enabling Conditions are also influential. | Specific knowledge about AI and pedagogical integration is key to teachers' intention to use it. |
| 2 | Q2-Q4 | Ayanwale, M. A., Sanusi, I. T., Adelana, O. P., Aruleba, K. D., & Oyelere, S. S. (2022). | Computers and Education: Artificial Intelligence, 3. | Teachers' readiness and intention to teach artificial intelligence in schools. | To explore the factors influencing teachers' intention to teach artificial intelligence (AI) in schools, and to understand teachers' willingness to implement AI in education. | The PLS-SEM method was used to analyze the relationships among various factors such as perceived usefulness, attitude, confidence, AI relevance, and behavioral intention of teachers. Data were collected from 368 Nigerian teachers. | Factors such as AI literacy, confidence in learning, and AI relevance were significant predictors of behavioral intention. Confidence in teaching AI and AI relevance significantly predicted teachers' intention to teach AI. | Anxiety does not significantly predict teachers' behavioral intentions. |
| | | | | | | | | The perceived usefulness of AI and AI for social good are significant predictors. |
| | | | | | | | | Trust, relevance, and social good strongly predict teachers' willingness to teach AI. |
| 3 | Q1-Q2 | Benvenuti, M., Cangelosi, A., Weinberger, A., Mazzoni, E., | Computers in Human Behavior, 148. | Artificial intelligence and human behavioral development: A | Explore how digitization and artificial intelligence (AI) can promote 21st-century skills such | Literature review using the PRISMA protocol, focusing on ar- | Integrating computational thinking, programming, and coding into school curricula is essential. Creativity can | IA can be a valuable tool for improving skills such as creativity, critical thinking, and problem-solving. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| | | Benassi, M., Barbaresi, M., & Orsoni, M. (2023). | | perspective on new skills and competencies acquisition for the educational context. | as creativity, critical thinking, problem-solving, and computational thinking in educational contexts. | ticles related to education, IA, and critical thinking. | enhance computational thinking, and AI can foster creativity. Critical thinking is crucial for problem-solving and can be enhanced through computational thinking and programming with the help of AI. | The interrelationship between creativity, computational thinking, and critical thinking is fundamental to effective learning.<br>Technology, including AI, robot tutors, and virtual reality, can promote more personalized and collaborative learning. |
| 4 | Q2-Q4 | Bozkurt, A. (2023). | Asian Journal of Distance Education, 18(1), 198-204. | Generative Artificial Intelligence (AI) Powered Conversational Educational Agents: The Inevitable Paradigm Shift. | Explore the use and impact of generative artificial intelligence, with a focus on ChatGPT, in education. | Not specified in the extracts provided. | Generative artificial intelligence, especially ChatGPT, has significant potential to transform teaching and learning methods. | The importance of preparing for an AI-dominated future in education.<br>The need to develop prompts engineering as a form of digital literacy.<br>The importance of adopting a critical and reflective stance towards the use of generative AI in education. |
| 5 | Q1-Q2 | Casal-Otero, L., Catala, A., Fernandez-Morante, C., Taboada, M., Cebreiro, B., & Barro, S. (2023) | International Journal of Stem Education, 10(1). | AI literacy in K-12: a systematic literature review. | Understand how artificial intelligence (AI) is being integrated into K-12 education globally, identifying learning experience approaches and theoretical perspectives. | Systematic literature review using Scopus, analyzing 179 articles focused on learning experiences and theoretical perspectives. | A growing interest in IA education in K-12 schools was identified, with a variety of approaches to teaching IA concepts to students. | Need for a competency framework to guide IA literacy proposals.<br>Importance of teacher training and systemic approaches to IA education.<br>IA literacy should enhance learning in core subjects and promote interdisciplinary and critical approaches. |
| 6 | Q2 | Chichekian & Benteux (2022). | Frontiers in Artificial Intelligence, 5. | The potential of learning with (and not from) artificial intelligence in education. | Explore the potential of artificial intelligence (AI) in education, focusing on the effectiveness of AI-driven technologies, the role of teachers, and contributions to the field of education. | Literature review, including meta-analyses on intelligent tutoring systems, self-determination theory in the classroom, and the impact of AI on teaching and learning. | Most research focuses on the optimization of AI systems rather than on the quality of learning outcomes. The need for more theoretical investigations and a pedagogical perspective in AI research in education is emphasized. | AI has the potential to improve learning outcomes and educational experience.<br>There is a lack of focus on the quality of learning outcomes and student experience in current research.<br>Teachers play a crucial role in integrating AI technologies to improve learning outcomes. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 7 | Q2 | Dimitriadou & Lanitis (2023). | Smart Learning Environments, 10(1). | A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in smart classrooms. | Explore the role of artificial intelligence (AI) and other emerging technologies in smart classrooms, highlighting both the benefits and challenges of their use in education. | Literature review related to emerging technologies in education, including AI, virtual reality (VR), augmented reality (AR), robotics, and adaptive learning systems. | Enhance the learning experience by supporting interactive experiences and real-time feedback. | AI and related technologies have a positive impact on education, improving interaction, engagement, and academic performance. |
| | | | | | | | Increased student and teacher engagement and performance through technologies such as VR/AR and robotics. | The challenges identified require attention to maximize the benefits of these technologies in educational settings. |
| | | | | | | | Identification of challenges such as equipment costs, need for teacher training, data privacy concerns, and biases in AI systems. | |
| 8 | Q2 | Gentile, M., Città, G., Perna, S., & Allegra, M. (2023). | Frontiers in Education, 8. | Do we still need teachers? Navigating the paradigm shift of the teacher's role in the AI era. | Examine the changing role of teachers in the age of artificial intelligence (AI) and propose a manifesto to guide this evolution. | Systematic analysis of the literature on the use of IA in education, focusing on the integration of technologies in teaching and learning. | A need for teachers to adapt to new technologies and teaching methods. | Teachers must develop digital skills and understand IA to effectively integrate it into their teaching practices. |
| | | | | | | | IA is transforming teacher-student relationships and teaching methods. | AI enables personalized learning and improves student monitoring. |
| | | | | | | | | There is an exponential growth in publications on the role of teachers and IA in education, especially in China. |
| 9 | Q2 | Karalekas, G., Vologiannidis, S., & Kalomiros, J. (2023). | Education Sciences, 13(1). | Teaching Machine Learning in K-12 Using Robotics. | Discuss the importance of and approaches to integrating educational robotics and ML in K-12 education. | Literature review and discussion of educational tools and platforms. | Identification of tools and platforms such as Scratch, Cognimates, Teachable Machine, and TensorFlow Playground. | Educational robotics and ML can make abstract concepts more tangible and enhance STEM education. |
| | | | | | | | Presentation of six AI-powered educational robots: Zumi, RoboMaster S1, ClicBot, Cozmo, MINDSTORMS Robot Inventor, and Cogbots. | Use of educational robots and proposed robotic arms to teach ML in secondary education classes. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 10 | Q1-Q2 | Kim, J., Lee, H., & Cho, Y. H. (2022). | Education and Information Technologies, 27(5), 6069-6104. | Learning Design to Support Student-AI Collaboration: Perspectives of Leading Teachers for AI in Education. | Explore the integration of Artificial Intelligence (AI) in education, focusing on student-AI collaboration, and how this can improve learning in K-12 schools. | It is not explicitly described in the excerpts provided but is inferred to be based on the exploration of teacher perspectives on student-AI collaboration. | Teachers view student-AI collaboration as a tool for achieving optimal learning objectives, emphasizing the importance of knowledge construction, interdisciplinary learning, authentic problem solving, and creative assignments. | The importance of student-AI collaboration in learning.<br>Need for systematic AIED policies to improve AI applications in education.<br>AI as a "learning companion" that provides instructional scaffolding. |
| 11 | Q2-Q4 | Kim, K., & Kwon, K. (2023). | Computers and Education: Artificial Intelligence, 4. | Exploring the AI competencies of elementary school teachers in South Korea. | To explore the experiences of elementary school teachers in South Korea teaching AI curricula and identify the competencies needed for effective implementation of AI education. | Surveys and interviews with elementary school teachers to collect quantitative and qualitative data on their experiences and competencies in teaching AI. | Twenty-two AI competencies were identified for elementary school teachers based on the TPACK framework. Teachers felt most confident in their pedagogical knowledge, followed by technological knowledge and content knowledge. | Teachers face difficulties in designing and implementing AI curricula due to a lack of training, infrastructure, and support.<br>Teacher confidence is higher in designing and implementing curricula that promote learning experiences with AI-based technologies.<br>Teachers recognize the importance of integrating AI concepts into various subjects and promoting hands-on activities for students. |
| 12 | Q1-Q2 | Lim, E. M. (2023). | Education and Information Technologies, 28(10), 12969-12995. | The Effects of Pre-Service Early Childhood Teachers' Digital Literacy and Self-Efficacy on Their Perception of AI Education for Young Children. | To examine the relationship between digital literacy, self-efficacy, and perceptions of AI (Artificial Intelligence) education for young children among prospective early childhood education teachers. | Surveys were conducted with 212 prospective early childhood education teachers, using descriptive statistics, correlation analysis, and hierarchical multiple regression analysis. | The means of digital literacy, self-efficacy, and perception of AI education were 3.43, 3.31, and 3.36 respectively, indicating a positive relationship between these variables. Self-efficacy measured the relationship between digital literacy and perception of AI education. | Digital literacy and self-efficacy have a positive impact on the perception of AI education for young children. Self-efficacy plays a mediating role between digital literacy and perception of AI education. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 13 | Q2-Q4 | Nazaretsky, T., Ariely, M., Cukurova, M., & Alexandron, G. (2022). | British Journal of Educational Technology, 53(4), 914-931. | Teachers' Trust in AI-Powered Educational Technology and a Professional Development Program to Improve It. | Improve teachers' confidence in AI technology through a professional development program. | The program included sessions on AI literacy, demystifying misconceptions, and how to integrate AI recommendations into pedagogy. In-service high school biology teachers in Israel participated, using an AI-powered assessment tool called AI-Grader. | Teachers showed an increase in confidence toward AI technology in education, leading to a greater willingness to use AI tools in their classrooms. | Providing procedural knowledge about AI and addressing misconceptions improves teachers' confidence in AI technology.<br>Transparency in how the AI makes recommendations and gives teachers control over these is crucial.<br>The importance of increasing both teachers' theoretical and practical knowledge of AI in educational contexts. |
| 14 | Q2 | Ng, D. T. K., Lee, M., Tan, R. J. Y., Hu, X., Downie, J. S., & Chu, S. K. W. (2023). | Education and Information Technologies, 28(7), 8445-8501. | A review of AI teaching and learning from 2000 to 2020. | Analyze trends in AI teaching and learning (AITL) research. | Formulation of objectives, review, and analysis of methodological approaches, fields of study, purposes, theories, platforms, and effects. | The most significant results of the study include the identification of methods and areas of study in AITL, and the analysis of trends and effects on education. The importance of understanding trends in AITL to improve the teaching and learning of artificial intelligence was confirmed. Notable trends were observed in the methodology used, fields of study addressed, and effects on education, suggesting growth and evolution in AITL research over time. | Increasing popularity of teaching artificial intelligence at primary/secondary educational levels and in non-computer-related universities.<br>Use of varied pedagogical approaches such as collaborative and project-based learning.<br>Application of various teaching tools such as MATLAB programming. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 15 | Q2 | Nja, C. O., Idiege, K. J., Uwe, U. E., Meremikwu, A. N., Ekon, E. E., Erim, C. M., Ukah, J. U., Eyo, E. O., Anari, M. I., & Cornelius-Ukpepi, B. U. (2023). | Smart Learning Environments (2023), 10 | Adoption of Artificial Intelligence in Science Teaching: From the Vantage Point of the African Science Teachers. | Explore the use of technology in education, including artificial intelligence, online learning environments, and the uptake of ICT by different age groups. Highlight factors influencing technology adoption by teachers and the impact on student learning outcomes. | Analysis of various studies on technology in education. | The most significant results of the study include that self-esteem, expected benefits, and ease of use have a significant impact on teachers' attitudes toward the use of artificial intelligence in science teaching. In addition, teachers' location of residence was found to not influence their intention to use artificial intelligence in teaching. Overall, it was confirmed that science teachers show high approval toward the integration of artificial intelligence in the science classroom. No significant differences in the results were observed as a function of teachers' gender, age, or location of residence. | Effective integration of technology in education is crucial. The importance of training teachers in the use of technology, especially in areas such as artificial intelligence, is highlighted. Challenges and opportunities in the implementation of technology in education are identified. |

# APPENDIX C

**Summary of the main findings of research question Q3**

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| 1 | Q3 | Cheng, E. C. K., & Wang, T. (2023). | Computers and Education: Artificial Intelligence, 5, 100171. | Leading digital transformation and eliminating barriers for teachers to incorporate artificial intelligence in basic education in Hong Kong. | Exploring the impact of digital leadership on the integration of Artificial Intelligence in Education (AIED), with a focus on overcoming teacher barriers. | A quantitative questionnaire survey was used, administered to 204 participants from primary and secondary schools. Confirmatory Factor Analysis (CFA) and reliability tests were used to validate the instrument. | Digital leadership significantly predicts all three approaches to AI application in education, while internal teacher barriers negatively predict learning about AI. | Digital leadership is crucial to promote AIED and overcome internal and external barriers for teachers.<br>Internal teacher barriers, such as perception and lack of training, negatively affect AIED integration. |
| 2 | Q3 | Dai, Y., Lin, Z., Liu, A., Dai, D., & Wang, W. (2024). | Journal of Educational Computing Research, 61(8), 159-186. | Effect of an Analogy-Based Approach of Artificial Intelligence Pedagogy in Upper Primary Schools. | Develop a scenario-based instrument to assess co-design expertise in humanitarian engineering and explore the use of analogies and metaphors in science education. In addition, investigates the teaching of artificial intelligence (AI) in K-12 classrooms and the importance of AI literacy. | Thematic analysis and analogy-based pedagogical approaches to teaching IA, compared to conventional direct instruction. | Teaching IA using a pedagogical approach that demystifies IA and uses analogies significantly improves students' understanding, performance, and interest in IA. Students who learned with the analogy-based approach outperformed those with conventional instruction in IA knowledge, skills, and ethical awareness. | The pedagogical approach involving IA demystification and the use of analogies is effective in teaching IA to upper elementary students.<br>Analogies help students better understand IA concepts and foster greater ethical awareness. |
| 3 | Q1-Q3 | El Hajj, M., & H. Harb (2023). | IAFOR Journal of Education, 11(2), 97-113. | Rethinking Education: An In-Depth Examination of Modern Technologies and Pedagogic Recommendations. | Explore the integration of technology in education through the Technological Pedagogical Content Knowledge (TPCK) framework, emphasizing student-centered learning. | Literature review on technology integration in education and analysis of teaching strategies using technology. | Technology-based education improves student learning by integrating technological tools into the teaching and learning process. | The critical importance of teachers in guiding and supporting student growth and success in technology-based learning environments. There is a need for ongoing professional development and training programs for teachers to effectively integrate technology into the classroom. |

| Nº. | Question | Author/year of publication | Journal | Title | Objectives of the study | Methodology | Most relevant results | Key findings/ conclusions |
|---|---|---|---|---|---|---|---|---|
| | | | | | Identify technological tools that facilitate interactive and engaging teaching strategies. | List of technological tools used to facilitate various teaching strategies. | Technology tools such as Tricider, AnswerGarden, MindMeister, among others, can be used to facilitate teaching strategies such as flipped classrooms, inquiry-based learning, and peer feedback. | These tools help create interactive and engaging learning experiences for students. They promote collaboration, critical thinking, and self-regulated learning skills. |
| 4 | Q3 | Yau, K. W., Chai, C. S., Chiu, T. K. F., Meng, H., King, I., & Yam, Y. (2023) | Education and Information Technologies (2023) 28:1041-1064 | A phenome graphic approach on teacher conceptions of teaching Artificial Intelligence (AI) in K-12 schools. | To investigate teachers' conceptions of teaching Artificial Intelligence (AI) in K-12 schools using a phenome graphic approach. | Interviews were conducted to identify six categories of teachers' conceptions of AI teaching. | The most significant results of the study include the identification of 6 categories of conceptions of Artificial Intelligence (AI) teaching in teachers. These categories cover aspects such as technological bridging, knowledge delivery, stimulation of interest, establishment of ethics, cultivation of skills, and intellectual development. | The key findings of this study reveal six categories of teachers' conceptions of AI teaching, from technological bridging to intellectual development. These insights into teachers' beliefs impact classroom practices and student learning, emphasizing the need for teacher training programs that support a deeper approach to AI teaching in education. |

# APPENDIX D

**Summary of the main findings of research question Q4**

| Nº. | Question | Author/Year of publication | Journal | Title | Objectives of the Study | Methodology | Most Relevant Results | Key Findings / Conclusions |
|---|---|---|---|---|---|---|---|---|
| 1 | Q4 | Abylkasymova, A. E., Shishov, S. E., Kalney, V. A., & Ryakhimova, E. G. (2022). | Journal of Higher Education Theory and Practice, 22(5), 201-206. | Influence of High-Tech Society on the Development of Modern Educational System. | To explore how high-tech society influences the development of the modern educational system, addressing the formation of a valid educational system, principles of interaction with high-tech education, effective methods and tools, and the role of machines in education. | Analysis of national and international academic papers. | A need to adapt the education system to the digital era by incorporating technologies such as VR/AR, mobile internet, and digital skills education. | The importance of developing digital skills for success in the high-tech market.<br>The need to go beyond basic digital literacy, including stability, IT skills, communication skills, and emotional intelligence. |
| 2 | Q2-Q4 | Ayanwale, M. A., Sanusi, I. T., Adelana, O. P., Aruleba, K. D., & Oyelere, S. S. (2022). | Computers and Education: Artificial Intelligence, 3. | Teachers' readiness and intention to teach artificial intelligence in schools. | To explore the factors that influence teachers' intention to teach artificial intelligence (AI) in schools, and to understand teachers' willingness to implement AI in education. | The PLS-SEM method was used to analyze the relationships among various factors such as perceived usefulness, attitude, confidence, AI relevance, and behavioral intention of teachers. Data were collected from 368 Nigerian teachers. | Factors such as AI literacy, confidence in learning, and AI relevance were significant predictors of behavioral intention. Confidence in teaching AI and AI relevance significantly predicted teachers' intention to teach AI. | Anxiety does not significantly predict teachers' behavioral intentions.<br>The perceived usefulness of AI and AI for social good is a significant predictor.<br>Trust, relevance, and social good strongly predict teachers' willingness to teach AI. |
| 3 | Q4 | Barakina, E. Y., Popova, A. V., Gorokhova, S. S., & Voskovskaya, A. S. (2021). | European Journal of Contemporary Education, 10(2), 285-296. | Digital Technologies and Artificial Intelligence Technologies in Education. | Explore the use of digital and artificial intelligence (AI) technologies in education, evaluating their benefits, risks, and impact on teaching, learning, and evaluation of students. In addition, it seeks to understand the legal regulations and international experiences in the implementation of these technologies. | Not specified in the text provided. | Benefits and risks of AI in education.<br>Varied experiences from different countries in the implementation of AI technologies in education.<br>Recommendations for the development of legal regulations in AI in education. | Despite advances in AI, most respondents still value the role of teachers in the learning process.<br>AI is seen as a tool to improve the quality of education, but it is crucial to consider the reliability and effectiveness of these technologies. |

| Nº. | Question | Author/Year of publication | Journal | Title | Objectives of the Study | Methodology | Most Relevant Results | Key Findings / Conclusions |
|---|---|---|---|---|---|---|---|---|
| 4 | Q2-Q4 | Bozkurt (2023). | Asian Journal of Distance Education, 18(1), 198-204. | Generative Artificial Intelligence (AI) Powered Conversational Educational Agents: The Inevitable Paradigm Shift. | Explore the use and impact of generative artificial intelligence, with a focus on ChatGPT, in education. | Not specified in the extracts provided. | Generative artificial intelligence, especially ChatGPT, has significant potential to transform teaching and learning methods. | The importance of preparing for an AI-dominated future in education.<br>The need to develop prompts engineering as a form of digital literacy.<br>The importance of adopting a critical and reflective stance towards the use of generative AI in education. |
| 5 | Q4 | Bozkurt, A., Xiao, J., Lambert, S., Pazurek, A., Crompton, H., Koseoglu, S., Farrow, R., Bond, M., Nerantzi, C., Honeychurch, S., Bali, M., Dron, J., Mir, K., Stewart, B., Costello, E., Mason, J., Stracke, C. M., Romero-Hall, E., Koutropoulos, A., … Jandric, P. (2023). | Asian Journal of Distance Education, 18(1), 53-130. | Speculative Futures on ChatGPT and Generative Artificial Intelligence (AI): A Collective Reflection from the Educational Landscape. | Explore the use and impact of artificial intelligence (AI), specifically ChatGPT, in education. | Systematic literature review and analysis of speculative narratives about possible futures with AI in education. | Widespread use of AI in education for tasks such as research, language learning, and personal support.<br>Concerns about ethics, privacy, and AI bias.<br>The potential of AI to improve or harm education and society. | AI can offer significant benefits in education, such as personalized learning and efficiency.<br>There are significant risks, including algorithmic bias, lack of creativity, and ethical concerns.<br>The need for a human-centered approach to integrating AI into education. |
| 6 | Q4 | Ipek, Z. H., Gözüm, A. I. C., Papadakis, S., & Kallogiannakis, M. (2023). | Educational Process: International Journal, 12(3), 26-55. | Educational Applications of the ChatGPT AI System: Systematic Review Research. | Investigate the impact of ChatGPT on education, exploring both the potential benefits and the ethical challenges and concerns. | A systematic review of the literature was performed, selecting 40 relevant studies using specific inclusion and exclusion criteria. | ChatGPT has the potential to transform education, offering benefits such as literature review, complex answer generation, personalized learning, and cyberbullying prevention. However, it also raises concerns about academic integrity and ethical issues. | ChatGPT can significantly enhance education through various applications. - There are legitimate concerns about deception, bias, and ethical and legal implications. |

| Nº. | Question | Author/Year of publication | Journal | Title | Objectives of the Study | Methodology | Most Relevant Results | Key Findings / Conclusions |
|---|---|---|---|---|---|---|---|---|
| 7 | Q2-Q4 | Kim, K., & Kwon, K. (2023). | Computers and Education: Artificial Intelligence, 4. | Exploring the AI competencies of elementary school teachers in South Korea. | To explore the experiences of elementary school teachers in South Korea teaching AI curricula and identify the competencies needed for effective implementation of AI education. | Surveys and interviews with elementary school teachers to collect quantitative and qualitative data on their experiences and competencies in teaching AI. | Twenty-two AI competencies were identified for elementary school teachers based on the TPACK framework. Teachers felt most confident in their pedagogical knowledge, followed by technological knowledge and content knowledge. | Teachers face difficulties in designing and implementing AI curricula due to a lack of training, infrastructure, and support.<br>Teacher confidence is higher in designing and implementing curricula that promote learning experiences with AI-based technologies.<br>Teachers recognize the importance of integrating AI concepts into various subjects and promoting hands-on activities for students. |
| 8 | Q4 | Lo, C. K. (2023). | Education Sciences, 13(4). | What Is the Impact of ChatGPT on Education? A Rapid Review of Literature. | Evaluate the performance of ChatGPT in different academic domains, its potential to improve teaching and learning, and associated problems. | A quick review of the literature on the use of ChatGPT in education. | ChatGPT showed outstanding performance in critical thinking and economics but struggled in law, medical education, and mathematics. | ChatGPT is useful for generating course materials and assessment tasks, and for helping students answer questions and summarize information.<br>Problems such as the use of biased data limited up-to-date knowledge, and concerns about plagiarism were identified. |
| 9 | Q2-Q4 | Nazaretsky, T., Ariely, M., Cukurova, M., & Alexandron, G. (2022). | British Journal of Educational Technology, 53(4), 914-931. | Teachers' Trust in AI-Powered Educational Technology and a Professional Development Program to Improve It. | Improve teachers' confidence in AI technology through a professional development program. | The program included sessions on AI literacy, demystifying misconceptions, and how to integrate AI recommendations into pedagogy. In-service high school biology teachers in Israel participated, using an AI-powered assessment tool called AI-Grader. | Teachers showed an increase in confidence toward AI technology in education, leading to a greater willingness to use AI tools in their classrooms. | Providing procedural knowledge about AI and addressing misconceptions improves teachers' confidence in AI technology.<br>Transparency in how the AI makes recommendations and gives teachers control over these is crucial.<br>The importance of increasing both teachers' theoretical and practical knowledge of AI in educational contexts. |

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| 9) Nurturing human intelligence in the age of AI: rethinking education for the future (2025) | DEVELOPMENT AND LEARNING IN ORGANIZATION (Article From : EMERALD) |

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Viewpoint

# Nurturing human intelligence in the age of AI: rethinking education for the future

Rosemary Luckin

Rosemary Luckin is based at CCM, University College London, London, UK.

## Introduction

In this article, I explore the profound impact of Artificial Intelligence (AI) on education and its implications for the future. I delve into the need for a fundamental shift in the current education systems to address the need to equip young people for their crucial role as the workforce of tomorrow. This viewpoint aims to provide practitioners with actionable insights on how to navigate the rapidly evolving landscape of AI in education.

## The disruption of AI in education

AI has emerged as a transformative force in various sectors, and education is no exception. AI has the potential to revolutionize education, enhancing teaching practices and personalizing learning experiences. One significant area is the creation of personalized learning experiences for students. AI-powered systems, such as Carnegie Learning, Aleks, Alelo and CenturyTech, can analyze student responses to questions and adapt learning materials to meet individual students' needs. These systems can help identify gaps in students' understanding and provide targeted feedback to help improve their learning outcomes. This personalized approach allows students to progress at their own pace, focusing on areas where they need additional support and challenging them in areas where they excel.

AI can also enhance teacher professional development and support, providing educators with real-time feedback on their teaching practices and helping them identify areas where they can improve. Tools like Sibme, TeachFX and Edthena use AI to analyze teaching interactions, providing valuable insights into teaching effectiveness and promoting reflective practice. This feedback enables teachers to refine their instructional strategies and create more engaging and effective learning environments.

Automation of administrative tasks is another area where AI can benefit the education sector. By leveraging AI technologies, schools can automate processes such as lesson planning and attendance tracking, freeing up teachers' time to focus on instruction and student support. This enables educators to dedicate more quality time to their students, fostering meaningful relationships and providing individualized guidance.

However, while AI holds great promise, it is important to approach its implementation in education with caution. It is crucial to strike a balance between leveraging AI's capabilities and preserving the unique human touch in education. AI should be seen as a tool to augment human intelligence rather than replace it. Educators play a vital role in guiding and supporting students, fostering critical thinking, creativity and empathy – qualities that are distinctively human and essential for navigating an AI-driven future.

Additionally, it is essential to address the potential ethical and social implications of AI in education. Privacy concerns, data security and algorithmic bias are important considerations that must be carefully managed. It is crucial to acknowledge and address the potential biases and inequalities that may arise. AI algorithms can inadvertently perpetuate biases present in the data they are trained on, which can lead to unequal opportunities and reinforce existing societal disparities. It is vital to ensure that AI systems are designed and deployed with fairness, transparency and inclusivity in mind. Collaborations between educators, policymakers and technologists can establish ethical guidelines and regulations that safeguard against bias and ensure equitable outcomes for all learners.

## Rethinking education systems

However, to fully reap the benefits of AI technologies and prepare young people for a workplace that will inevitably be replete with AI, we must acknowledge the current shortcomings of our education systems. One of the key challenges in the current schooling system is its focus on rote learning and standardized assessments. Students are often rewarded for their ability to memorize facts and regurgitate them during exams. This approach fails to cultivate critical thinking skills and stifles creativity. To address this, we need to shift the focus from memorization to fostering independent thinking and problem-solving abilities.

Education systems must place far greater emphasis on developing high-level thinking capabilities in students. "Learning Mastery" and "Knowledge Mastery," where students not only acquire knowledge but also learn how to navigate and interpret their own mental processes are essential.

Learning Mastery refers to a student's ability to understand and regulate their own learning processes effectively. It focuses on developing metacognitive skills, which involve students being aware of their own thinking, understanding their strengths and weaknesses, and actively monitoring and adjusting their learning strategies. By fostering learning mastery, students become more self-directed learners who can set goals, evaluate their progress and make informed decisions about their learning. They develop the ability to reflect on their learning experiences, identify areas where they need improvement and seek out appropriate resources and strategies to enhance their learning outcomes. Promoting learning mastery involves teaching students how to think about their thinking, or metacognition. This can be done through explicit instruction on metacognitive strategies, encouraging self-reflection and self-assessment, and providing opportunities for students to develop their problem-solving and critical-thinking skills.

Knowledge Mastery refers to a student's depth of understanding and expertise in a particular subject or domain. It goes beyond mere memorization of facts and focuses on developing a deep conceptual understanding of the underlying principles and connections within a field of knowledge. Knowledge mastery involves cultivating higher-order thinking skills such as critical analysis, synthesis and evaluation. Students are encouraged to think critically about information, challenge assumptions and apply their knowledge to real-world contexts. It also involves developing the ability to transfer knowledge and skills across different domains, allowing students to apply their understanding in diverse situations. To foster knowledge mastery, educators can employ active learning strategies that engage students in meaningful and authentic tasks, such as project-based learning, problem-based learning and inquiry-based learning. These approaches promote deep learning, where students actively construct knowledge through exploration, collaboration and reflection.

The concepts of Learning Mastery and Knowledge Mastery are intertwined, as they complement and reinforce each other. By developing learning mastery, students become more effective learners, enabling them to develop a deep understanding of subjects and domains, thereby achieving knowledge mastery. Together, these concepts emphasize the importance of nurturing students' metacognitive abilities and promoting a deep understanding of content, enabling them to become lifelong learners who can adapt and thrive in an ever-changing world. By equipping students with the skills to regulate their thinking, generate original ideas and differentiate truth from fiction, we enable them to adapt and evolve in an ever-changing world.

## The vital role of educators in preparing young people for the future

As we look ahead, the impact of AI on young people cannot be overstated. Educational policies must be responsive and adaptable, encouraging innovation and collaboration between educational institutions, government bodies and industry stakeholders. It is crucial to invest in the professional development of teachers, providing them with the necessary training and support to leverage AI tools effectively. Additionally, curriculum frameworks should be revised to integrate AI literacy, digital citizenship and ethical considerations into the educational journey of young learners.

Practitioners play a vital role in shaping the future of education. They must actively engage with AI technologies and explore ways to integrate them into the learning process. Professional development programs should be designed to equip educators with the necessary skills to effectively utilize AI tools for personalized learning experiences. By providing training and support, teachers can be empowered to leverage AI as a tool to enhance their instructional practices.

AI has an additional role that is often overlooked – it can help us to redefine success in education as well as cultivate future-proof skills. One of the critical areas where AI can bring about a transformation is in redefining how we measure success in education. The traditional focus on standardized tests and grades often overlooks crucial aspects of a student's development, such as creativity, problem-solving skills and social-emotional intelligence. AI-powered assessment tools can provide a more holistic understanding of a student's abilities, capturing their strengths and areas for improvement beyond mere test scores. This shift in assessment practices enables educators to tailor instruction to meet individual needs and foster a well-rounded education.

## Conclusion

AI presents both exciting opportunities and challenges for education. In the coming years, AI will continue to transform our lives, the workplace and the educational landscape. The future of education lies in harnessing the power of AI while nurturing and celebrating the unique capabilities of human intelligence. By reimagining the schooling system, prioritizing high-level thinking and preparing young people for the demands of tomorrow's workforce, we can ensure a positive and prosperous future for society. Educational practitioners have a crucial role to play in this journey, bridging the gap between leading-edge research and practice to shape a future where AI and human intelligence coexist harmoniously. Through well-designed professional development programs, accessible AI education and targeted regulation, we can create an education system that empowers individuals to thrive in an AI-driven world. Education is not just about acquiring knowledge; it is about nurturing the human qualities that make us uniquely intelligent.

*Keywords:*
Ethics,
Education,
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Teacher professional development,
Personalized learning,
Future-proof skills

## References

Fadel, C., Bialik, M. and Trilling, B. (2015), *Four-Dimensional Education: The Competencies Learners Need to Succeed*, Center for Curriculum Redesign, Boston, MA.

Luckin, R. (2017), "Towards artificial intelligence-based assessment systems", *Nature Human Behaviour*, Vol. 1 No. 3, pp. 1-3.

Luckin, R. (2018), *Machine Learning and Human Intelligence: The Future of Education for the 21st Century*, UCL Institute of Education Press, London.

Selwyn, N. (2019), *Should Robots Replace Teachers? AI and the Future of Education*, Polity Press, Cambridge.

Webb, C., Luckin, R. and Ecoff, E. (2023), "Ethical principles for the development and application of artificial intelligence in K-12 education", in Lee, W.O., Brown, P., Goodwin, A.L. and Green, A. (Eds), *International Handbook on Education Development in Asia-Pacific*, Springer, Singapore.

Zhao, Y. (2018), *What Works May Hurt: Side Effects in Education*, Teachers College Press, New York, NY.

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# Nurturing partnerships to support data access for impact forecasts and warnings: Theoretical integration and synthesis

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ABSTRACT

This paper presents a synthesis and theoretical integration of findings from a research project that explored the data needs and sources for implementing impact forecasts and warnings for hydrometeorological hazards. Impact forecasts and warnings (IFW) have received global attention in recent years as they offer a novel way of improving the communication of hazards and risks. The fundamental idea behind IFWs is to enable warning services to meaningfully communicate the anticipated outcomes, consequences, or impacts of the hazard interacting with society or the environment by incorporating knowledge about the underlying and dynamic exposure and vulnerability of people and assets. One key question for IFW implementation is about data needs and sources to inform IFWs.Using the Grounded Theory Methodology, we address the question *"How can partnerships and collaboration better facilitate the collection, creation, and access to hazard, impact, vulnerability, and exposure data for IFWs?"* Our findings point to partnerships and collaboration as a necessary strategy for implementing IFWs. Implementation requires accessing various types and sources of hazard, impact, vulnerability, and exposure data to assess and communicate the potential impacts of hydrometeorological hazards. Partnerships and collaboration facilitate the sharing of and access to required data and knowledge. Based on our findings, we provide recommendations to increase interagency communication and partnerships for IFWs and disaster risk reduction, such as making cohabitation arrangements between agencies, running joint training scenarios, and encouraging meteorological services and emergency responders to co-define tailored warning thresholds.

**Acronym/Abbreviation**

| | |
|---|---|
| ACC | Accident Compensation Corporation |
| CDEM | Civil Defence and Emergency Management |
| CRI | Crown Research Institute |
| DHB | District Health Board |
| DOC | Department of Conservation |
| DRR | Disaster Risk Reduction |

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|---|---|
| EM | Emergency Management |
| EQC | Earthquake Commission |
| ES-GTM | Evolved-Straussian Grounded Theory Methodology |
| EWS | Early Warning System |
| FENZ | Fire and Emergency New Zealand |
| GEMA | Geographic Emergency Management Aotearoa (formerly NZGIS4EM) |
| GIS | Geographical Information System |
| GIS4EM | Geographical Information System for Emergency Management (now GEMA) |
| GNS Science | Te Pū Ao Institute of Geological and Nuclear Sciences Limited |
| Gov. | Government |
| GTM | Grounded Theory Methodology |
| GWE | Global Weather Enterprise |
| HIVE | Hazard, Impact, Vulnerability, and Exposure |
| Hyd. | Hydrological |
| IFRC | International Federation of Red Cross and Red Crescent Societies |
| IFW | Impact Forecast and Warning |
| IFWS | Impact Forecasting and Warning System |
| LINZ | Toitū Te Whenua Land Information New Zealand |
| MBIE | Ministry of Business, Innovation, and Employment |
| Met. | Meteorological |
| MetOffice | United Kingdom Meteorological Office |
| MetService | Meteorological Service of New Zealand Limited – Te Ratonga Tirorangi |
| MCDEM | Ministry of Civil Defence and Emergency Management (now NEMA) |
| MfE | Ministry for the Environment |
| MPI | Ministry of Primary Industries |
| Nat. | National |
| NEMA | National Emergency Management Agency (formerly MCDEM) |
| NHP | Natural Hazards Partnership |
| NIWA | National Institute of Water and Atmospheric Research |
| NZ | Aotearoa New Zealand |
| NZTA | Waka Kotahi NZ Transport Agency |
| RC | Regional Council |
| Reg. | Regional |
| RNC | Resilience to Nature's Challenges Kia manawaroa – Ngā Ākina o Te Ao Tūroa |
| Stats NZ | Statistics New Zealand |
| SOE | State-Owned Enterprise |
| UK | United Kingdom |
| USA | United States of America |
| UN | United Nations |
| UNDRR | United Nations Office for Disaster Risk Reduction (formerly UNISDR) |
| UNISDR | United Nations International Strategy for Disaster Reduction (now UNDRR) |
| VGI | Volunteered Geographic Information |
| WMO | World Meteorological Organization |

## 1. Introduction

Impact forecasts and warnings (IFW) have received global attention in recent years to improve the communication of hazards and associated risks. This is due in part to the World Meteorological Organization's (WMO) encouragement for member nations to implement them as a way of reducing losses and impacts from hydrometeorological events [1–3]. This is because notable historic events have exposed communication gaps between meteorologists, warning services, and target audiences, resulting in widespread losses [1,4–6]. This communication gap is a result of both technical failings and human behaviour [7]. Research has shown that meteorologists and warning services do not typically consider the warning audiences' current state of vulnerability and exposure at the time of the warning or at the expected time of impact, due to lack of knowledge and lack of easy access to this information [1,8]. For example, the ultramarathon tragedy on May 22, 2021 in Baiyin, Gansu Province, China where 21 race runners died due to exposure to high winds combined with low temperatures and precipitation highlighted the lack of consideration around the race runners' exposure to what normally would have been a low-impact weather event [6]. This and other notable examples show a need for warning systems to consider the current exposure and vulnerability of people at the time and location of the hazard, and to translate the hazard-based warning into an impact warning such that appropriate protective action decisions can be made [6].

The fundamental idea behind IFWs is to enable warning services to meaningfully communicate the anticipated impacts of the hazard by incorporating knowledge about the underlying and dynamic exposure and vulnerability of people and assets [6,8]. To date, much research has been conducted to understand the challenges and barriers for implementing IFWs (e.g., Refs. [9–13]); to explore the data needs and data sources for implementation and evaluation (e.g., Refs. [3,8,14–17]); to develop and evaluate hazard and impact models and risk-based approaches (e.g., Refs. [18–23]); and to understand public perceptions of IFWs (e.g., Refs. [24–31]).

These studies point to several outstanding questions that influence whether and how warning services can implement IFWs. For example, results around the efficacy of IFWs suggest that impact information alone is less effective at positively influencing intentions to take protective action than including action advice alongside the impact information [28]. This raises questions around whether the costs of implementing IFWs outweigh the perceived benefits of them [12]. A lack of useful data was also identified as a barrier to implementation [8,12,23]. Consequently, the WMO advises that the first step of IFW implementation is to explore possible data sources [3]. This led to investigations into existing and potential data sources to fill these data gaps [16,17,32].

Throughout 2018–2022 a multi-phased project was conducted to investigate the data needs and sources for IFWs for hydrometeorological hazards in Aotearoa New Zealand. The overarching project involved four central studies: exploring Volunteered Geographic Information (VGI; [14]); data uses and gaps [8]; sources of hazard, impact, vulnerability, and exposure (HIVE) data [32]; and exploring data governance issues [8,15]. The design and key findings of these studies are summarised in Table 1.

Central to the findings summarised in Table 1, is the important, and often missing, component of partnerships and collaboration required for implementing IFWs. Partnerships and collaboration are an established concept in DRR and EWS literature; they contribute to a resilient society by facilitating the sharing of knowledge and resources [33,34]. Garcia and Fearnley [35] argued that integrated partnerships that support constant communication are needed to achieve effective use of scientific information for EWS. Furthermore, partnerships are described as “the foundation for an effective” IFW system in the WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services Part II, where it is “essential” to understand partnerships, mandates, and governance structures for successful IFW systems ([3], pp. viii-ix). In support of this literature, the 2018–2022 research conducted by Harrison et al [3,8,14,15] found partnerships and collaboration to be critical for IFWs yet missing in some cases and contexts throughout Aotearoa New Zealand and abroad. Examples of the stakeholders likely to be involved in an IFW system and the required partnerships were consolidated from the literature and are summarised in Table 2, with New Zealand-specific examples provided for context.

In Aotearoa New Zealand, different agencies have the mandated responsibility for issuing warnings for specific hazards. The New Zealand Meteorological Service (i.e., the MetService) is the appointed National Meteorological Service for Aotearoa New Zealand and is thus responsible for providing basic public weather forecasts and issuing warnings of hazardous weather affecting land and marine areas [36]. Flood warnings, however, are the responsibility of Local and Regional Councils, with support from the MetService, the National Institute of Water and Atmospheric Research (NIWA), and Emergency Management agencies [37]. Reports have noted the need

**Table 1**
Summary of related papers previously published for this project, including the research questions and key findings of each paper.

| Paper | Research Questions | Key Findings |
|---|---|---|
| Harrison et al. [14] | What are the current and potential uses of Volunteered Geographic Information (VGI) for severe weather warnings? | • Various forms of VGI, from geo-located social media, crowdsourcing platforms, participatory mapping/participatory Geographic Information Systems (GIS), and local knowledge, have roles to play in all components of a hydrometeorological early warning system (EWS).<br>• Some forms of VGI are more useful for specific EWS components than are others.<br>• VGI processes can bridge the gap between EWSs and audiences of warnings by incorporating local knowledge and personal experiences from stakeholders into the EWS components. |
| Harrison et al. [8] | What are the data uses and gaps for IFWs? | • There is a growing need for creating, gathering, and using impact, vulnerability, and exposure data for IFW systems.<br>• Each data type (hazard, impact, vulnerability, and exposure) has relevant application in various components of the Warning Value Chain.<br>• Different approaches can be used for impact forecasting and defining impact thresholds using objective models and subjective impact-oriented discussions depending on the data available.<br>• There is a growing need to identify, model, and warn for social and health impacts. |
| Harrison et al. [32] | What are the sources of hazard, impact, vulnerability, and exposure (HIVE) data? | • Various sources for HIVE data are available for implementing hydrometeorological IFW systems, but are collected, stored, and managed by different agencies, introducing barriers to use of and access to the data.<br>• GIS-based tools and mobile devices are examples of technological advancements for collecting and creating HIVE data to ensure the data are useful and useable for multiple purposes.<br>• Priorities, motivation, and interest within organisations influence how data are collected and used.<br>• There is a tension between the timeliness and trustworthiness of data needed for emergency response and warnings. For example, timely data collected from social media and other crowdsourcing platforms are perceived as less trustworthy than other more official and traditional sources of data, which may not be available as quickly.<br>• Strategies for addressing challenges and barriers for collecting and using HIVE data include garnering support and buy-in and strong community leadership for overcoming conflicting management priorities or a lack of motivation and interest. |
| Harrison et al. [15] | How can HIVE data governance, access, and sharing be improved for hydrometeorological hazards in New Zealand? | • There is a need for improved data governance of hazard, impact, vulnerability, and exposure data.<br>• There is a need for building and nurturing stronger partnerships to continue building trust between stakeholders for sharing data.<br>• Systematic and standardised data collection approaches using GIS-based tools can address data integration challenges. |

**Table 2**
Summary stakeholders likely to be involved in an IFW system.

| | List of Stakeholders | Description and examples from Aotearoa New Zealand | Information and data sharing |
|---|---|---|---|
| **Providers of hydro-meteorological forecasts, warnings, and advice** | Meteorological Service | The meteorological service monitors meteorological conditions and produces forecasts based on their monitoring. When thresholds are met for hazardous meteorological conditions that are expected to impact society, a watch or warning might be issued. For example, the NZ MetService issues yellow watches, and orange and red warnings depending on the anticipated impacts. | Meteorological observations, forecasts and warnings. |
| | Local and Regional Councils | Local and regional councils in Aotearoa New Zealand monitor river levels and forecast and warn for river and surface flooding, and produce forecasts and warnings for floods. They might be in contact with the meteorological service to partake in the meteorological warning decision-making process. | Hydrogeological hazard observations, forecasts and warnings, knowledge of antecedent conditions contributing to vulnerability and exposure. |
| | Emergency Management Agencies | Emergency Management agencies are responsible for pushing out and acting on forecasts and warnings. They might also add action advice to the warning message and may also be involved in the warning decision-making process. These agencies also collect impact information in the form of intelligence for situational awareness. | Evaluate vulnerabilities, identify potential impacts and proper mitigation actions, share expertise, collect intelligence. |
| | Scientific Institutions | Scientists and scientific institutions like GNS Science, NIWA, and universities may aid in the development of hydrometeorological and hydrogeological models for forecasts as well as in the design of warning messages and advice. They might also produce impact forecasts such as the rainfall-induce landslide impact forecasts produced by RiskScape in response to the Auckland Anniversary heavy rainfall event and Cyclone Gabrielle in February 2023 [35]. | Improve and develop technical processes/ equipment (e.g., modelling), share data sources/datasets, share expertise and advice. |
| **Users of forecasts, warnings, and advice** | The publics | Respond to the forecasts, warnings, and advice. | Identify thresholds, vulnerability, and exposure. |
| | Agricultural sector | Respond to the forecasts, warnings, and advice. | Identify thresholds, vulnerability, and exposure. |
| | Critical Infrastructure (e.g., roads, rail, aviation, power, water, telecommunications) | Respond to the forecasts, warnings, and advice. | Identify thresholds, vulnerability, and exposure. |
| | Public Health Sector | Respond to the forecasts, warnings, and advice. Provide tailored advice where appropriate. | Identify thresholds, vulnerability, and exposure. |
| | Businesses | Respond to the forecasts, warnings, and advice. | Identify thresholds, vulnerability, and exposure. |
| | Transportation | Respond to the forecasts, warnings, and advice. Provide tailored advice where appropriate. | Identify thresholds, vulnerability, and exposure. |
| | Public Transit | Respond to the forecasts, warnings, and advice. | Identify thresholds, vulnerability, and exposure. |
| | The media | Disseminate forecasts, warnings, and advice. Document and report on the impacts. | Impacts documented in news reports. |
| | Non-government organisations (NGOs) | Respond to the forecasts and warnings, plan and allocate response and recovery efforts and aid. | Vulnerability and exposure assessments, mitigation actions, impacts documented during recovery support. |

for greater collaboration between organisations and increased data and information sharing for improving flood warnings and flood mitigation (e.g., [38–41]).

Furthermore, other agencies are responsible for issuing forecasts and warnings for other non-hydrometeorological hazards. The National Emergency Management Agency (NEMA) holds authority for issuing tsunami warnings, with support from GNS Science [42,43]. GNS Science is responsible for monitoring and delivering hazard information pertaining to earthquake, volcanic activity, and landslides).

Emergency Management agencies also play a key role in disseminating forecast and warning messages, initiating response plans including evacuations, and providing localised advice to their jurisdiction [42]. Strong partnerships, collaboration, and coordination across these multiple agencies are thus required for a fully integrated multi-hazard EWS where the impacts of cascading and concurrent hazards are considered, assessed, and communicated efficiently and consistently across agencies (e.g., Ref. [44]).

This current paper thus provides a theory grounded in qualitative data and results, previously presented by Harrison et al. [3,8,14,15], to answer the research question *"How can partnerships and collaboration facilitate better collection, creation, and access to HIVE data for IFWs?"* This theory (presented in Section 3) also provides strategies for building and nurturing such partnerships to support stakeholders both in and outside of Aotearoa New Zealand involved IFWs and DRR efforts.

## 2. Methodology

We used a qualitative Grounded Theory Methodology (GTM) to conduct this exploratory study [45,46]. More specifically, we employed the Evolved Straussian GTM (ES-GTM; [45,47,48]) visualised in Fig. 1. Under the ES-GTM we began with an initial literature

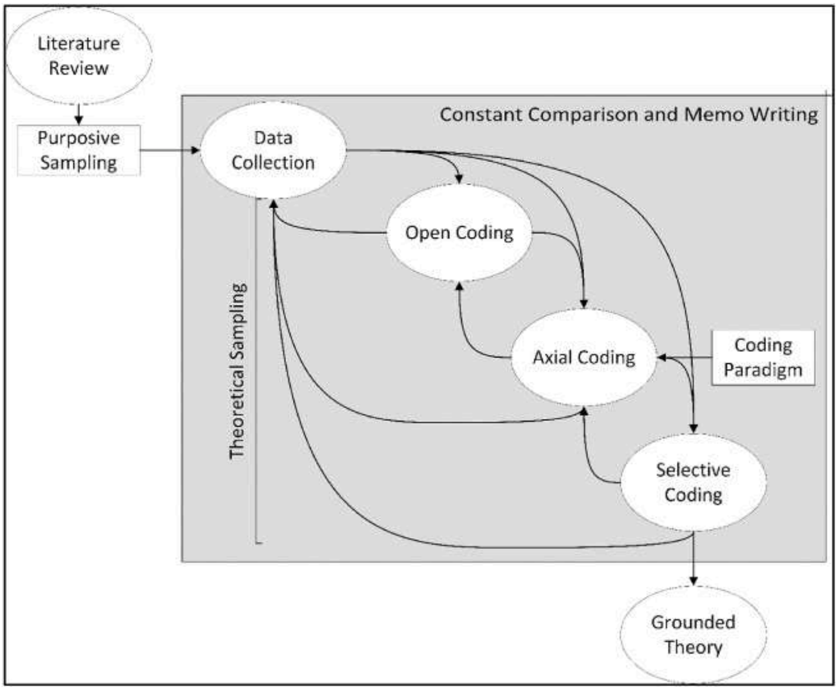


**Fig. 1.** Conceptual framework of the ES-GTM analytical process employed in this research. Figure created by the first author of this paper based on interpretations of Corbin and Strauss [45,47], Charmaz (2006), and Glaser and Strauss [46].

review to provide context and justification for the study and inform the research question [49]. Data collection and analysis commenced concurrently using purposive and theoretical sampling techniques to target future data collection by identifying clues, gaps, and uncertainties in need of further exploration [46,50].

### *2.1. Data collection methods*

We used interviews and workshops to collect qualitative data for this study. We conducted interviews in the first phase to develop an understanding of the current perspectives on IFW systems and the associated data needs in New Zealand and abroad. In the second phase, we ran three workshops to triangulate the interview results. Data collection took place from November 2018 to May 2021.

#### *2.1.1. Interviews*

We initially used a purposive sampling method [50] to target and recruit interviewees based on their roles in hydrometeorological risk communication, response, and their use of impact, vulnerability, and exposure data. Recruitment was targeted towards individuals or organisations that issue hydrometeorological warnings, and/or collect, create, share, use, or manage HIVE data for hazard and risk management. We identified potential participants through our networks and contacted them directly via e-mail. After the initial interviews were conducted, theoretical sampling guided the rest of the data collection process whereby we recruited participants who were knowledgeable or experienced in themes that emerged from previous interviews [46].

We interviewed thirty-nine (39) individuals. The interviews ranged in length from 45 to 90 min. Interviews were audio-recorded and transcribed verbatim for analysis. Due to the COVID-19 pandemic recruitment was limited towards the final months of data collection as many of the target participants were responding to COVID-19. Interviews were conducted both in person and virtually. Details of the interview structure, questions, and participant profiles are reported in previous publications for this project [8,15,32].

#### *2.1.2. Workshops*

We conducted three 2-h long workshops to diversify the qualitative dataset and to triangulate the research findings [45,51]. Emergency Management officials and staff from the New Zealand Meteorological Service (herein referred to as the MetService) participated in one regional workshop each for Auckland and Southland, New Zealand. Researchers and scientists from GNS Science involved in hazard and risk management in Aotearoa New Zealand participated in the third workshop. GNS Science is a Crown Research Institute (CRI) of New Zealand and is heavily involved in the management of natural hazards and risks across the country by providing scientific evidence and advice for response, planning, and policy [52,53]. The workshops were held virtually due to COVID-19 concerns.

Twenty individuals participated in all three workshops. Four people participated in the Auckland workshop, representing Auckland Emergency Management, the MetService, and Auckland Council from the Planning Department and the Healthy Waters Department. Five people attended the Southland workshop, representing Southland Regional Council from the Geographical Information Systems (GIS) team, the Hydrology team, the Communications and Engagement team, and Emergency Management Southland.

Eleven people from GNS Science attended the third virtual workshop to represent a portion of the community of science in New Zealand.

We used the web-based whiteboarding platform, Mural,[1] to facilitate the workshops. We mapped out a virtual whiteboard as shown in Fig. 2 with specific questions and activities for the participants to navigate. We asked participants to provide feedback on an impact, vulnerability, and exposure data framework that we developed from the interviews. We then asked workshop participants to identify data requirements and sources for IFWs based their roles. In the third activity we asked the participants to identify one to two datasets or data sources that they think are important, to outline the life track of the data, and to describe how they understand what impacts are occurring or could occur from a hydrometeorological hazard. In the fourth activity participants identified alternative uses beyond IFWs for the datasets or data sources that they identified in activity three. In the last activity we investigated the application of the framework: whether the participants would use it, why or why not, and how. The workshops were audio recorded through Microsoft Teams, and data from the virtual sticky notes were entered into a spreadsheet for further analysis.

### 2.2. Analytical techniques

We utilised constant comparison, memo-writing, diagramming, and coding techniques to analyse the qualitative data as shown in Fig. 1 [45]. We used Nvivo 12, a qualitative data analysis software package that facilitates data management, idea management, data querying, graphical modelling of ideas and concepts, and data reporting [54].

#### 2.2.1. Memo-writing and diagramming

Memos are "written records of analysis" ([45], p. 57). Memo-writing and diagramming were regularly used throughout the data collection and analysis for this study. When the lead author noticed common themes in the interviews, a memo was written to identify the theme and begin to understand the potential significance of the theme.

The lead author regularly diagrammed her mental map of key themes, concepts, and relationships that emerged during an interview and compared the resulting diagrams to each other. Through this process, the lead author developed a data collection and process flow for IFWs, presented in Harrison et al. [8], that was validated during the workshops. The theory presented in this paper (Fig. 5 in Section 3) was a further result of the diagramming and theoretical integration process presented herein.

#### 2.2.2. Coding and constant comparison

Coding involves "denoting concepts to stand for meaning" in the qualitative data ([45], p. 57), and occurred in three stages in this study, following ES-GTM: open coding, axial coding, and selective coding. Interview transcripts were loaded into Nvivo for this analytical process.

In the *open coding* stage (see Fig. 1), open codes were developed directly from the data (i.e., in vivo), and with reference to the literature. We performed constant comparison by comparing the data pieces (e.g., sentences, paragraphs) for similarities and differences; similar parts were assigned the same code and different parts were assigned a different code [55]. The open coding process was documented with theoretical memos and in the code descriptions [45].

The resulting open codes were grouped into categories using constant comparison and memo writing. For example, interviewees identified data sources from the various social media platforms which the lead author coded according to the social media platform (e.g., Twitter, Facebook, Snap Chat), and grouped into a 'Social Media' category. The 'Social Media' and 'Crowdsourcing' categories were then grouped into 'Alternative or unofficial data sources', while another category was created for 'Official and Trusted Data Sources' to capture the data sources that interviewees deemed as such (e.g., Emergency Management-led damage surveys and impact assessments, emergency calls, and media reports). This relational process allowed for different dimensions of categories to be identified through the memo-writing process, such as trustworthiness of the data.

After the data were broken up into concepts and categories, we used *axial coding* (see Fig. 1) to piece the data back together to form categories [55] and to investigate the relationships between the categories [48]. For this stage, we found Strauss and Corbin's [48] 1990 coding paradigm to fit the data better than more recent variations of the coding paradigm as explained by Harrison et al. [15,32]. For example, the 1990 coding paradigm includes "Causal", "Intervening", and "Contextual Conditions" ([48], p. 99), while the most recent variation of the coding paradigm only provides "Conditions" ([45], p. 158). We found that Causal, Intervening, and Contextual Conditions better explain the data by identifying drivers (i.e., causal conditions) and challenges in the categories and phenomena, as visualised in Fig. 3. For example, past disaster events such as the 2010–2011 Canterbury earthquake sequence were identified in interviews as a driver (i.e., causal condition) for improving data collection and management within the Emergency Management sector in Aotearoa New Zealand. Contextual conditions were determined to be high-level influences of overall practice, particularly governance and cultural conditions in Aotearoa New Zealand. Results from the axial coding process were digitised into a spreadsheet for further aggregation and shifting of codes and categories. Significant themes were then highlighted for reporting.

Through this process we identified two phenomena as the subjects under study [48]. The first phenomenon was *IFW Systems*, and the second was *Hazard, Impact, Vulnerability, and Exposure (HIVE) Data*. These two phenomena were respectively analysed and reported by Harrison et al. [8,15,32]. The two phenomena and their associated categories and open codes are visualised in Fig. 4.

The *Impact Forecasting and Warning (IFW) Systems* phenomenon consists of two categories: IFW Implementation and IFW Data Needs. The codes for the IFW Implementation category relate to defining and understanding IFW systems and what is needed to implement them. The codes in the IFW Data Needs category relate to identifying the different types of data needs for IFWs (e.g., hazard, impact, vulnerability, and exposure data), and justification and uses for these different data types in the IFW systems context.

[1] https://www.mural.co/.

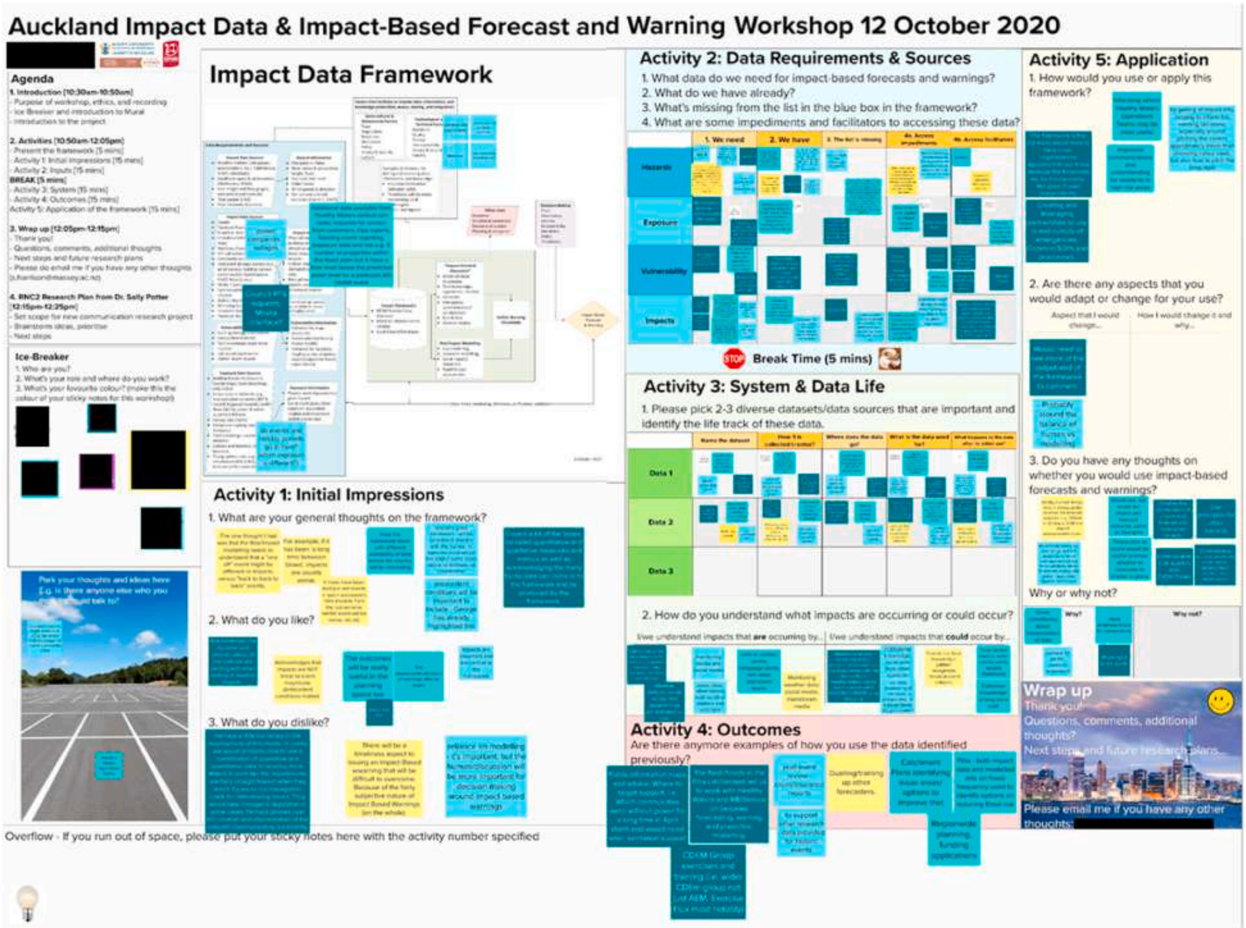


**Fig. 2.** Image of the virtual whiteboard the was populated using Mural during the workshop with participants from Auckland Council, Auckland Emergency Management, and the MetService on October 12, 2020.

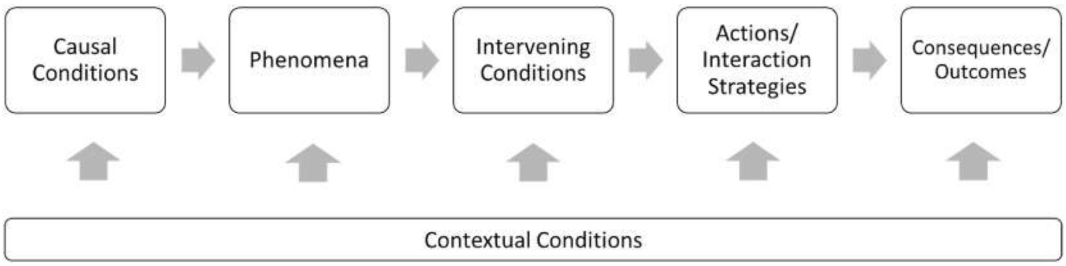


**Fig. 3.** The axial coding paradigm [48] used to relate the categories and identify the phenomena.

The *Hazard, Impact, Vulnerability, and Exposure (HIVE) Data* phenomenon consists of two categories: Data Sources and Collection, and Data Governance, Access and Sharing. During the axial coding process these categories were identified based on a common theme between the open codes. These three category topics arose organically by the participants and were discussed at length. Thus, they were deemed to be important enough to be their own categories. These three categories are inherently linked to each other. For example, in the Data Sources and Collection category, two codes emerged regarding the existence of many datasets and sources: 'More data is available or exists than we think' and 'Various stakeholders that create, manage, share, access, use data'. These two codes led to the idea that these datasets and sources exist and are collected by various sources, then there must be a way to share these data. As such, the lead author interrogated the qualitative interview data with questions around data sharing and access, resulting in codes identifying drivers for sharing data. Further questions arose around why these data are not being used very well, which led to identifying challenges with accessing these data (i.e., intervening conditions), as well as issues of Data Management and Governance, where the data are not managed or maintained very well, making it difficult to share and effectively use the data. Questions were asked around the potential causes of data management and governance issues that are inhibiting HIVE data collection and sharing practices in NZ.

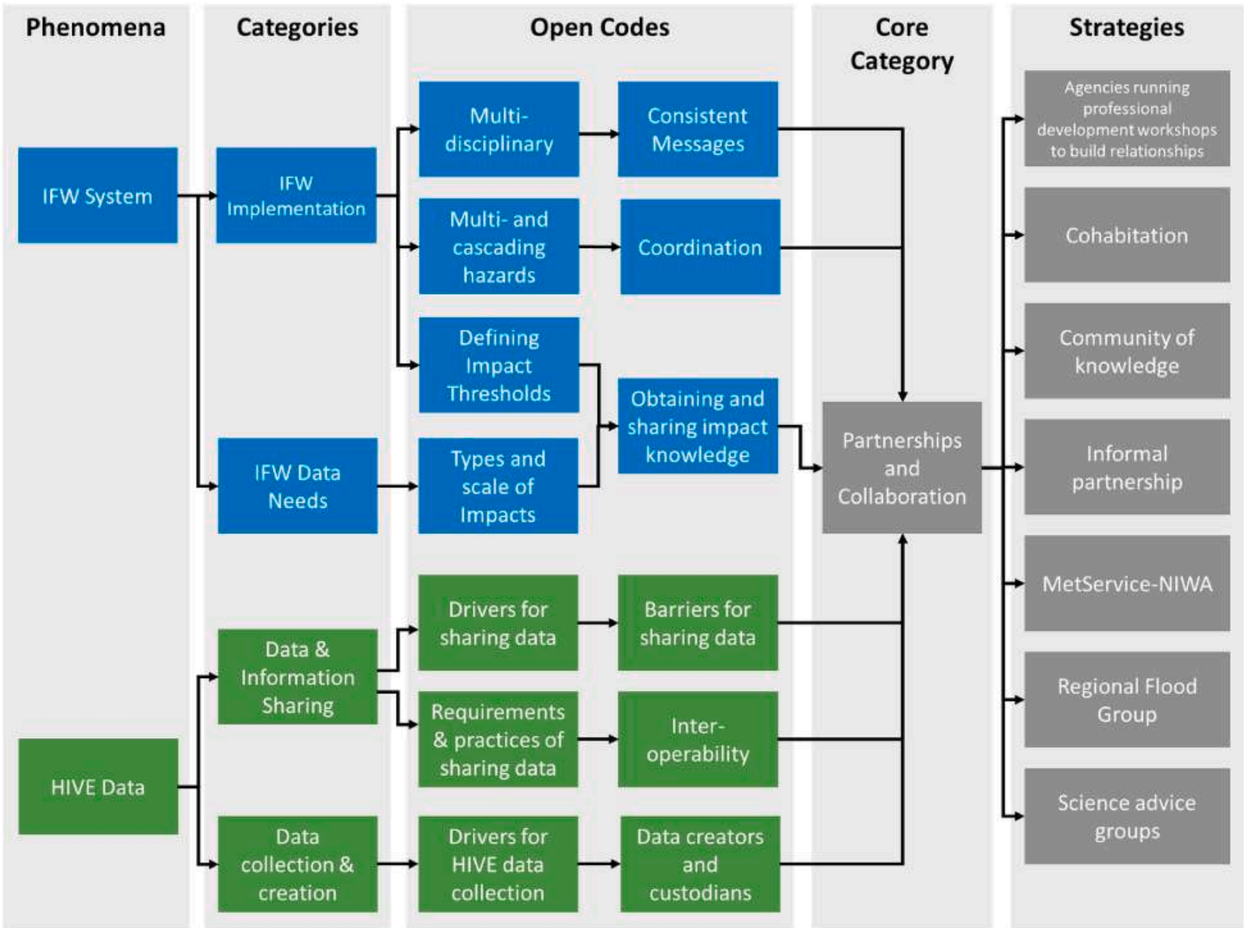


**Fig. 4.** Relationships between the two phenomena under study and the core category. The blue, green, and grey boxes represent codes and categories developed throughout the analysis. The blue boxes represent the IFW System phenomenon and associated categories and codes. The green boxes represent the HIVE Data phenomenon and associated categories and codes. The dark grey boxes represent the core category of Partnerships and Collaboration. The arrows portray the coding hierarchy and the relationship to the core category of Partnerships and Collaboration. The light grey boxes indicate the ES-GTM methodological component.

Through *selective coding* (see Fig. 1) we related all categories to the core category to develop the grounded theory. The core category "incorporates or supersedes other categories in explanatory importance and hence is 'elevated' to the status of an important concept" ([56], p. 7). Here, we validated relationships and refined categories [55]. Through continuous reflection, constant comparison, re-assignment of codes and categories, memo-writing, and diagramming, we established the core category and integrated all categories into one cohesive theory [55], described in Section 3.

We identified *Partnerships and Collaboration* as the core category in this study, as we found it weaves through all resulting themes and categories. Partnerships and Collaboration appear to be essential for both IFW Systems and HIVE Data, as shown by the open codes visualised in Fig. 4. For the IFW System Phenomenon, discussions with participants showed that the process of defining impact thresholds requires partnering with agencies and sectors (e.g., transportation, flood management, health, insurance, agriculture) that possess the knowledge needed to define these impact thresholds.

For the HIVE Data phenomenon, the concept of Partnerships and Collaboration cut across two categories: (1) Data and Information Sharing, and (2) Data Collection and Creation. In the first category, *'Data and Information Sharing'*, cooperation and collaboration were identified as strategies for facilitating data sharing between the various agencies that possess the data. In the second category, *'Data Collection and Creation'*, cooperation and collaboration were identified as strategies for establishing data collection standards across agencies. The need for this arose from the idea of agencies collaborating with each other after an event to co-design data collection forms such that the resulting data suit various users' needs (Met. Research NZ. J; Risk Modelling NZ. C).

Other codes relating to partnerships and collaboration were created outside of the direct relation to these two phenomena that were grouped together and elevated to the core category of Partnerships and Collaboration, as shown in the dark grey boxes in Fig. 4.

The integration of the findings described in Section 3 are structured around these two phenomena and how they relate back to the core category of Partnerships and Collaboration.

### 2.3. Ethical considerations

A 'low risk' ethics clearance was obtained prior to data collection in 2018. All participants remain anonymous and are assigned an alphabetic code (A, B, C, etc.), identified only by area of expertise and/or practice (e.g., Meteorology, Emergency Management, Data Management), sector (e.g., Private, Governance), location (e.g., NZ or International), or governance level (e.g., National, Regional, Local) as shown in Table 3. The acronyms and abbreviations in Table 3 are as follows: Meteorology (Met.), Emergency Management (EM), New Zealand (NZ), Geographic Information Systems (GIS), Regional (Reg), Government (Gov.), Early Warning System (EWS), International (Int.).

## 3. Integration of findings

Results regarding the two phenomena in this study have been previously published by Harrison et al. [8,15,32]. This paper aims to integrate the findings from the previous papers with the core category of *Partnerships and Collaboration* and situate these results in the context of the literature [57]. This integration is the final stage of ES-GTM where the interrelationships between the phenomena, categories, and core category are elaborated and related back to the literature [58]. The intent is to extend the literature and demonstrate the scholarly contribution of the Grounded Theory [59]. Next, we define the core category with its properties and dimensions and relate it back to the two phenomena and the wider body of literature on partnerships in DRR. We conclude the study and outline the limitations in Section 4.

### 3.1. Partnerships and collaboration core category defined

Based on the two phenomena under study in this research we define the core category of Partnerships and Collaboration as formal and informal, bottom-up or top-down approaches to establishing, building, and/or nurturing working relationships with stakeholders involved in the communication of and response to hydrometeorological hazards, to allow for defining warning thresholds; creating

**Table 3**
Interviewee codes.

| Interviewee Code | Position | Classification | Location |
|---|---|---|---|
| Agriculture/Rural NZ. A | Agriculture policy coordinator | Agriculture/Rural | NZ |
| Data Management Gov. NZ. Nat. A | Senior Resilience Advisor | Data Management | NZ |
| Data Management Private NZ. B | Geospatial Specialist | Data Management | NZ |
| Data Management Research NZ. C | GIS Specialist | Data Management | NZ |
| Data Management Private NZ. D | GIS Specialist | Data Management | NZ |
| Data Management Gov. NZ. Nat. E | Head of Data | Data Management; Governance | NZ |
| EM. NZ. Reg. A | Director | Emergency Management | NZ |
| EM. NZ. Reg. B | Controller | Emergency Management | NZ |
| EM. NZ. Reg. C | Controller | Emergency Management | NZ |
| EM. NZ. Reg. D | Principal Science Advisor | Emergency Management | NZ |
| EM. NZ. Reg. E | Principal Advisor Strategy and Partnerships | Emergency Management | NZ |
| EM. NZ. Reg. F | GIS Lead | Emergency Management; Data Management | NZ |
| EM. Gov. NZ. Nat. G | Senior Hazard Risk Management Advisor | Emergency Management; Governance | NZ |
| EM. NZ. Reg. H | Emergency Management Advisor | Emergency Management | NZ |
| EM. NZ. Nat. I | First Responder | Emergency Management | NZ |
| EM. Gov. NZ. Nat. J | National Operations Manager | Emergency Management; Governance | NZ |
| EM. NZ. Reg. K | Regional Manager | Emergency Management | NZ |
| EM. NZ. Reg. L | Emergency Management Advisor | Emergency Management | NZ |
| EM. NZ. Reg. M | Group Controller | Emergency Management | NZ |
| Health NZ. Reg. A | Respiratory Doctor | Public Health | NZ |
| Hyd. Gov. NZ. Reg. A | Flood EWS Programme Manager | Hydrology; Governance | NZ |
| Lifelines NZ. Reg. A | Civil Engineer | Lifelines | NZ |
| Loss Modelling Research NZ. A | Economist | Loss Modelling; Research | NZ |
| Met. Int. A | Science Manager | Meteorology | Inter-national |
| Met. Int. B | National Manager Disaster Mitigation Policy | Meteorology | Inter-national |
| Met. Int. C | Senior Policy Officer | Meteorology | Inter-national |
| Met. Int. D | Senior Social Scientist | Meteorology | Inter-national |
| Met. Int. E | Consultant Meteorologist | Meteorology | Inter-national |
| Met. NZ. F | Senior Meteorologist | Meteorology | NZ |
| Met. NZ. G | Communications | Meteorology | NZ |
| Met. NZ. H | Public Relations | Meteorology | NZ |
| Met. Int. I | Division Chief/Meteorologist | Meteorology | Inter-national |
| Met. Research NZ. J | Meteorologist | Meteorology; Research | NZ |
| Met. NZ. K | Senior Meteorologist | Meteorology | NZ |
| Met. Private NZ. L | Head Weather Analyst | Meteorology | NZ |
| Risk Modelling NZ. A | Risk Modeller | Risk Modelling | NZ |
| Risk Modelling NZ. B | Risk Modeller | Risk Modelling | NZ |
| Risk Modelling NZ. C | Risk Modeller | Risk Modelling | NZ |
| Risk Modelling NZ. D | Risk Modeller | Risk Modelling | NZ |

consistent warning messages; sharing knowledge and data of hazards, impacts, vulnerability, and exposure; collecting appropriate and useful data; and managing said data towards the implementation of an impact forecasting and warning system.

The concepts and the theory on which the above definition is based are represented visually in Fig. 5, which places Partnerships and Collaboration in the middle, supported by its properties and dimensions (discussed next, in Section 3.2). Partnerships and Collaboration were found to play a key role in both the IFW System phenomenon and the HIVE data phenomenon. This will be discussed in Sections 3.3 and 3.4, citing examples from the previous papers and additional evidence in the interview and workshop data. Evidence from interviews is referenced using the interviewee codes presented in Table 3, for example 'Met. Research NZ. J' for participant J in the meteorological research field in New Zealand. References to the workshops are formatted as either 'Auckland Workshop', 'Southland Workshop', or 'Research Community Workshop'. Examples of how Partnerships and Collaboration threads throughout this study are listed in Table 4. This aligns with the literature, which demonstrates that partnerships and collaboration are critical in both research and practice for disaster preparedness, planning, and response [60–63].

### 3.2. Properties and dimensions of the core category: partnerships and collaboration

The *Partnerships and Collaboration* core category consists of several properties and dimensions shown in Table 5. Properties are "characteristics that define and describe concepts" ([45], p. 220), and dimensions are variations within those properties [45]. Three properties were identified to frame the core category: types of partnerships, the directional approach, and strategies for building partnerships. Dimensions were identified for each of these properties. For example, formal and informal partnerships are the dimensions of the 'types of partnerships' property. These properties and their respective dimensions are summarised in Table 5 and will be discussed next, with direct references to the findings reported in previous related papers and to additional interview and workshop data.

#### 3.2.1. Types of partnerships

The first property of *Partnerships and Collaboration* is types of partnerships and collaboration, incorporating the dimensions of formal and informal partnerships.

In the context of this research, a **formal partnership** is defined as one that has been formally established (e.g., mandated, and/or formally outlined and agreed upon in writing) with clear roles and responsibilities between partners and distinct objectives for the partnership. Alternatively, an **informal partnership** is one that has formed rather spontaneously, typically in response to an event to

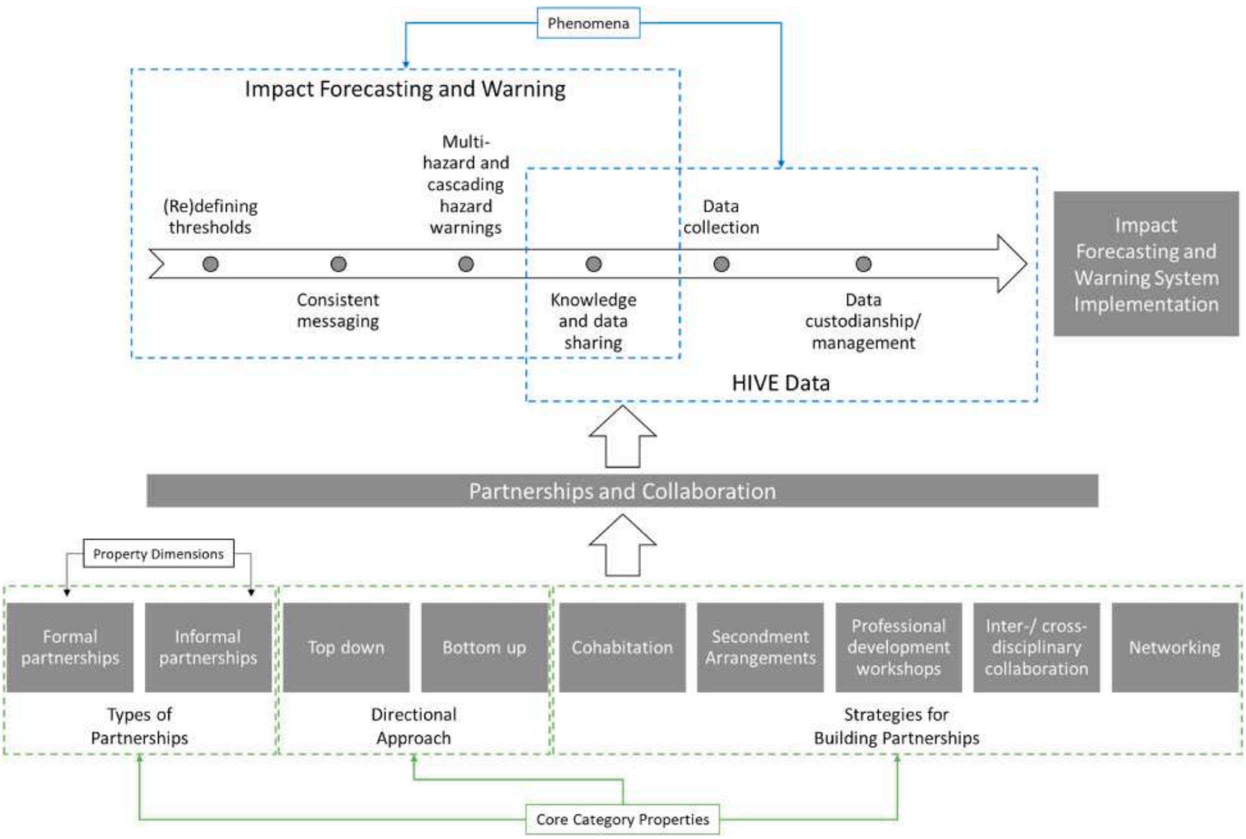


**Fig. 5.** Integrative diagram of the theory resulting from this study. The figure centres around the *Partnerships and Collaboration* core category for implementing an Impact Forecasting and Warning System. The two phenomena studied in this research (Impact Forecasting and Warnings, and HIVE Data) are outlined in blue. The properties and their dimensions of the core category are outlined in green. The core category is presented in the middle, with arrows linking the properties and dimensions to the two phenomena.

**Table 4**
Examples of themes relating to the Partnerships and Collaboration core category from the main results of each paper published to date.

| Paper Reference | Key findings relating to Partnerships and Collaboration |
|---|---|
| Harrison et al. [8] | Partnerships and collaboration used throughout the EWS:<br>• Hazard forecasting (e.g., initial discussions with MetService and hydrologists).<br>• Impact forecasting (e.g., sharing data between agencies to support impact modelling in the UK Natural Hazards Partnership (NHP), and conducting impact-oriented discussions across stakeholders such as when the Southland Red Warning was issued, and for forecasting the impacts of ex-tropical cyclone Debbie and ex- Tropical Cyclone Cook).<br>• Impact warning (e.g., defining impact thresholds like the UK MetOffice co-producing an impact matrix with stakeholders and updating warnings based on feedback form the stakeholders).<br>• Co-design of an EWS with the target audiences.<br>• Need for coordinated multi-disciplinary collection of human/social impact data.<br>• Cross-sector collaboration for integrating dynamic exposure and vulnerability data. |
| Harrison et al. [32] | Partnerships and collaboration are needed to:<br>• Reduce unwillingness to share data, which may be due to a lack of trust between agencies.<br>• Garner support and buy-in across regional stakeholders to allocate resources for better data collection.<br>• Support community leadership to drive innovation. |
| Harrison et al. [15] | Partnerships and collaboration help to:<br>• Clarify roles and responsibilities, guidance in fulfilling tasks (e.g., Stats NZ helping NEMA manage their loss database).<br>• Facilitate data sharing practices.<br>• Develop integration strategies for seamless data sharing (e.g., developing the Common Operating Picture collaboratively to identify common needs and build trust and partnerships between agencies). |

**Table 5**
Summary of the properties and dimensions of the partnerships and collaboration core category.

| Property | Dimensions | Description |
|---|---|---|
| **Types of Partnerships** | • Formal<br>• Informal | Formal and informal partnerships exist for IFW implementation and for collecting, using, and managing HIVE data. A formal partnership is one that has been established with clear roles and responsibilities between partners and defined objectives for the partnership. An informal partnership is one that has formed rather spontaneously, typically in response to an event, to fill an immediate gap, and the roles and responsibilities are not mandated by an authoritative body or document. |
| **Directional Approach** | • Top-down<br>• Bottom-up | The directional approach to form partnerships and collaborations refers to the motivation or drivers for the partnerships and collaboration. The top-down direction involves political guidance and a mandate to form the partnership and collaboration, while a bottom-up approach results in self-organised partnerships and collaboration. |
| **Strategies for Building Partnerships** | • Networking<br>• Professional Development<br>•Cohabitation<br>• Secondment arrangements<br>• Multi-disciplinary collaboration | Five strategies were identified for strengthening and building relationships that can result in informal and formal partnerships and collaboration and can facilitate either a top-down or bottom-up approach. |

fill an immediate gap, and where the roles and responsibilities are not stipulated by an authoritative body or document. The Natural Hazards Partnership (NHP) in the United Kingdom (UK) is an example of a formal partnership developed for providing authoritative and consistent hazard, impact, and risk information to responders and governments [64]. This partnership consists of 17 UK public service agencies and was a result of a post-event review of the 2007 UK summer floods that identified the need for a national framework for reducing risks from natural hazards on the delivery of essential services [64,65].

In Aotearoa New Zealand, no formal partnership like the UK NHP was identified over the course of this study. Instead, formal partnerships were found to exist in the form of science advice groups for non-hydrometeorological hazards, such as the New Zealand Volcanic Science Advisory Panel (NZVSAP; [66]), and the New Zealand Tsunami Expert Panel, as described by Harrison et al. [15]. These partnerships formed in response to gaps in services and communication that were observed from disasters that occurred both within and outside of New Zealand [15]. The purpose of the NZVSAP and the roles and responsibilities of associated members have been clearly identified in the Terms of Reference (see Ref. [66]). The formation of NZVSAP builds on prior regional volcanic science advisory groups, the oldest of which was Egmont Volcanic Advisory Group (EVAG)/Taranaki Seismic and Volcanic Advisory Group (TSVAG) formed in the 1990's [67,68]. EVAG/TSVAG was set up primarily to develop relationships around the newly (at the time) formed seismic network and to bring those data streams and interpretation together [67]. While these groups consist primarily of scientists who provide science advice to Emergency Management agencies in Aotearoa, New Zealand, other groups must be included for response and operations planning. For example, during the 2012 Tongariro eruption crisis, several other sectors became involved in the response, even though they were not initially identified or included in practice scenarios prior to the event [69]. These were the health, agriculture, and veterinary sectors [69].

No such formal science advice group was found in the course of this research for hydrometeorological hazards in Aotearoa New Zealand. However, the Resilience to Nature's Challenges Kia manawaroa – Ngā Ākina o Te Ao Tūroa (herein referred to as RNC) research programme has offered an avenue for starting this conversation. RNC was launched in 2015 and is funded by the Ministry of Business, Innovation and Employment [70]. RNC is a successor to the former Natural Hazards Research Platform, which was a 10-year research programme that funded natural hazards research in Aotearoa, New Zealand and "helped researchers and end-users work more closely together" [71]. A key objective of RNC is to promote innovative and collaborative research to build resilience to the natural hazards in Aotearoa, New Zealand [72]. RNC is composed of eight themes: Rural, Urban, Mātauranga Māori, Built Environment, Earthquake and Tsunami, Coastal, Volcano, and Weather and Wildfire. One participant in this study "always thought the [Natural Hazards Research Platform] was a pretty good vehicle for encouraging collaboration" (Met. Research NZ. J). This participant hopes "[RNC] does the same", indicating that the leaders of the Weather and Wildfire theme "try to be as inclusive as possible in terms of people developing their plans" and act as a "coordination point" for researchers to align with them and with each other (Met. Research NZ. J). This is reflective of the identified need to build interdisciplinary research teams for rapid response disaster research [60,63]. The RNC Weather and Wildfire theme may offer a potential mechanism for building both formal and informal partnerships for hydrometeorological hazard research and mitigation. Still, this may be difficult to implement in practice with no authoritative agency involvement, funding, or mandate [63]. The RNC programme will be ending in June 2024, with no clear next steps for future long-term collaborative research funding.

While few formal partnerships were found to exist in Aotearoa New Zealand specifically for hydrometeorological hazards, informal partnerships exist. One example is between the MetService and regional hydrologists, as described by Harrison et al. [8,15]. This form of partnership relies on the quality of the relationships between the MetService forecasters and meteorologists and the regional hydrologists, which can be influenced by staff turnover, training, interpersonal characteristics. This is considered an informal partnership because it has not been mandated and no guidance has been written to define roles and responsibilities [73,74]. It is a practical strategy developed to meet the need, and to support decision-making for forming and issuing hydrometeorological warnings. An important aspect influencing the types of partnerships and collaboration identified here (formal and informal), is the directional approach adopted when forming those partnerships.

#### 3.2.2. Directional approach

The directional approach to form partnerships and collaborations refers to the motivation or drivers behind it. Top-down and bottom-up are the two directions (i.e., property dimensions) that were identified in the analysis of the interviews and workshops. The **top-down approach** would involve political guidance and a mandate to form the partnership and collaboration, while a bottom-up approach results in self-organised partnerships and collaboration [75]. Thus, formal partnerships are usually created using a top-down approach where a governing body mandates the formation of a partnership, such as the NHP in the UK [64], and makes funding available [62]. Alternatively, informal partnerships usually arise from a **bottom-up approach** where potential partners might self-organise to meet a common need [75]. The Geographic Emergency Management Aotearoa (GEMA) group, formerly named NZGIS4EM and described by Harrison et al. [15], is an informal partnership that was formed from the bottom-up to facilitate effective collaboration and coordination during disaster response efforts, and to build a large community of practice for the GIS and emergency management sector in New Zealand. GEMA played a fundamental role in the coordination of staff and geospatial data in the response to Cyclone Gabrielle in 2023 [76].

Establishing mandates and funding structures by authoritative bodies would further support the establishment of partnerships that enable various groups to effectively collaborate with minimal barriers [60,63]. Both top-down and bottom-up approaches might use some strategies, described next, to build new or strengthen existing partnerships, and build up evidence to obtain funding to sustain the partnerships.

#### 3.2.3. Strategies for building and strengthening partnerships and collaboration

Five strategies were identified for building and strengthening partnerships and collaboration for IFW implementation and HIVE data collection, creation, and use. These strategies (i.e., property dimensions) are **networking, professional development, cohabitation, secondment arrangements, and multi-disciplinary collaboration**.

**Networking** was identified in the interviews as a strategy for building and strengthening partnerships and collaboration (EM. Gov. NZ. Nat. J). A technical or science advisory group like the NZVSAP and the New Zealand Tsunami Expert Panel may be useful for hydrometeorological hazards in Aotearoa, New Zealand to enable further understanding and consistent communication of the risks and impacts of these hazards (EM. Gov. NZ. Nat. J). This may also facilitate more efficient data access and sharing practices [60]. According to the participants in this study, forming such a group in Aotearoa, New Zealand for hydrometeorological hazards requires building and nurturing relationships by attending national conferences such as the National Emergency Management Agency (NEMA) Conference, NZ Meteorological Society Conference, NZ Hydrological Society Conference, etc., where attendees may test ideas together, garner support, and seek buy-in from higher-level decision- and policymakers (EM. Gov. NZ. Nat. J). For example, MetService staff might attend the NEMA conference, and Emergency Management agencies and council staff might attend the NZ Meteorological Society and the NZ Hydrological Society conferences. This kind of networking may act as a 'catalyst' for sparking connections to bring concepts forward into policy [77,78].

Agencies that often work together, such as the MetService, councils (e.g., hydrologists), and Emergency Management agencies, can also nurture their working relationships by running **professional development** workshops together and hosting these workshops at their own agencies, thereby creating a boundary organisation where agencies can build an understanding of each other's operational processes and create an interactive channel for transferring knowledge (EM. NZ. Reg. K; [79]). One regional Emergency Management agency indicated that the MetService used to host such visits with their group, which they found valuable for nurturing their relationship (EM. NZ. Reg. K). Past workshops held by researchers from CRIs were also seen as beneficial for keeping practitioners up to date on current research efforts and innovations (EM. NZ. Reg. K). These practices are akin to running scenario exercises to build relationships in advance of disaster events, for effective decision-making and communication [80]. Such exercises have proven highly beneficial for building and nurturing partnerships and collaboration for DRR [68,69,81,82].

**Cohabitation** is a strategy that has been employed overseas to improve flood forecasting and warnings [64,83]. Cohabitation occurs when experts from different disciplines operate from the same location. Co-location and cohabitation have been proposed to allow for the integration of broader expertise and to improve consistency and coordination in multi-hazard warning systems [84]. One such example is the co-location of the Environmental Agency Hydrologists in the UK MetOffice via the Flood Forecasting Centre formed in 2009 to allow for direct and rapid communication between hydrologists and meteorologists [85]. Another example, while not warnings-specific, is the Christchurch Justice & Emergency Services Precinct in Aotearoa New Zealand, where all justice and emergency services are located together in central Christchurch for better integration and coordination of these services [86]. When asked if cohabitation was an option to ease warning communication in Aotearoa New Zealand, our NEMA participant (EM. Gov. NZ. Nat. J) indicated that it could be done in a bottom-up fashion where the MetService and Emergency Management agency/ies and council(s) make their own cohabitation arrangements. This has been done between the NZ MetService and Auckland Council, where a MetService meteorologist sits in the Auckland Emergency Management office. Similarly, a co-author of this paper is co-located with a regional Emergency Management agency. However, the participant indicated that it might be more effective if some political direction was given from the top, for example, if a bill (i.e., a proposed law) were introduced or an existing bill was appended to say that this should be done (EM. Gov. NZ. Nat. J). Doing so would be difficult due to agencies' internal politics, funding sources, operational practices, and governance structures (EM. Gov. NZ. Nat. J). Thus, a starting point would be to look at the governance arrangements of each agency, for example the MetService, NEMA, CRIs, Emergency Management agencies, etc. and determine "how you would bring, and not bring the organisations together, [put] some of their functions together or instruct them" to achieve something together (EM. Gov. NZ. Nat. J).

**Secondment arrangements** are another approach to facilitating cohabitation (either in person or virtual due to shifts to working from home as a result of the COVID-19 pandemic) and growing partnerships in the science-policy interface (e.g., Refs. [87–89]). Secondment arrangements involve the temporary transfer of an employee from one agency to another. These arrangements between government agencies and research institutions have been uncommon in Aotearoa New Zealand until recently. For example, since late 2021, another co-author of this paper was seconded to a Crown Entity to support risk communication efforts, with other researchers in the DRR space in Aotearoa New Zealand taking up secondments with government agencies and crown entities such as NEMA and [90] to develop partnerships and strengthen relationships to enable more collaborative approaches to reducing risk in the country [90–92]. These arrangements indicate a growth of bridging science and central government. Such growth might be possible at the council level too.

Collaboration between scientists from **different disciplines** (e.g., risk modellers and social scientists) is a needed strategy for ensuring that data collection is comprehensive and accurate, and so that the risk and impact assessments of hydrometeorological hazards go beyond the built environment and extend into social human impacts [8]. This further reflects proposals for building interdisciplinary teams for disaster response research [60] and to support integrated transdisciplinary risk assessment and management processes [61]. Platforms like RNC can enable this kind of collaboration by providing a channel for researchers to engage with each other. Doing so enables knowledge co-production to support collaborative, adaptive, and robust policies [61].

The core category of Partnerships and Collaboration, consisting of the above properties and their respective dimensions, was found to thread through the two phenomena studied in this project (IFW Systems and HIVE Data). Examples of how Partnerships and Collaboration relates to IFW Systems and HIVE Data are discussed next.

### *3.3. Partnerships and collaboration in the impact forecasting and warning systems phenomenon*

Partnerships and Collaboration thread throughout the IFW Systems phenomenon as an integral action/interaction strategy [48] for implementing IFWs. Partnerships and Collaboration enable the important practice of sharing data and knowledge between agencies [15]. Sharing data and knowledge through partnerships and collaboration can then facilitate (re-)defining impact thresholds for an IFW system and can ensure that messages are consistent across agencies. These actions of sharing data and knowledge, (re-)defining impact thresholds, and producing consistent warning messages emerged from codes relating to the IFW phenomenon. Examples of how Partnerships and Collaboration enable these actions in the IFW phenomenon are provided next.

#### *3.3.1. Sharing data and knowledge*

Various agencies possess the knowledge and data needed for IFWs, as reported by Harrison et al. [32] and visualised in Fig. 6. Fig. 6 displays the agencies that were identified by participants as those that possess HIVE data for hydrometeorological hazards and impacts in Aotearoa New Zealand, as reported by Harrison et al. [32]. Each leaf of the Venn diagram represents data partners for one of the four data types: hazard, impact, vulnerability, and exposure. The agencies identified by Harrison et al. [32] for collecting or possessing datasets from each data type are placed within each leaf. For example, the MetService was identified as possessing hazard, impact, and vulnerability knowledge and data in various forms: they continuously monitor and collect observational data on meteorological hazards, they monitor severe weather impacts reported in the media, and they possess tacit knowledge of regional vulnerabilities to certain meteorological hazards such as knowing that Auckland is particularly vulnerable to north-easterly winds [8]. They use this information to inform their decisions to issue a warning and how to emphasise and communicate the associated threats. In another example, Data Ventures, a commercial data brokerage branch of Statistics New Zealand (typically referred to as Stats NZ, New

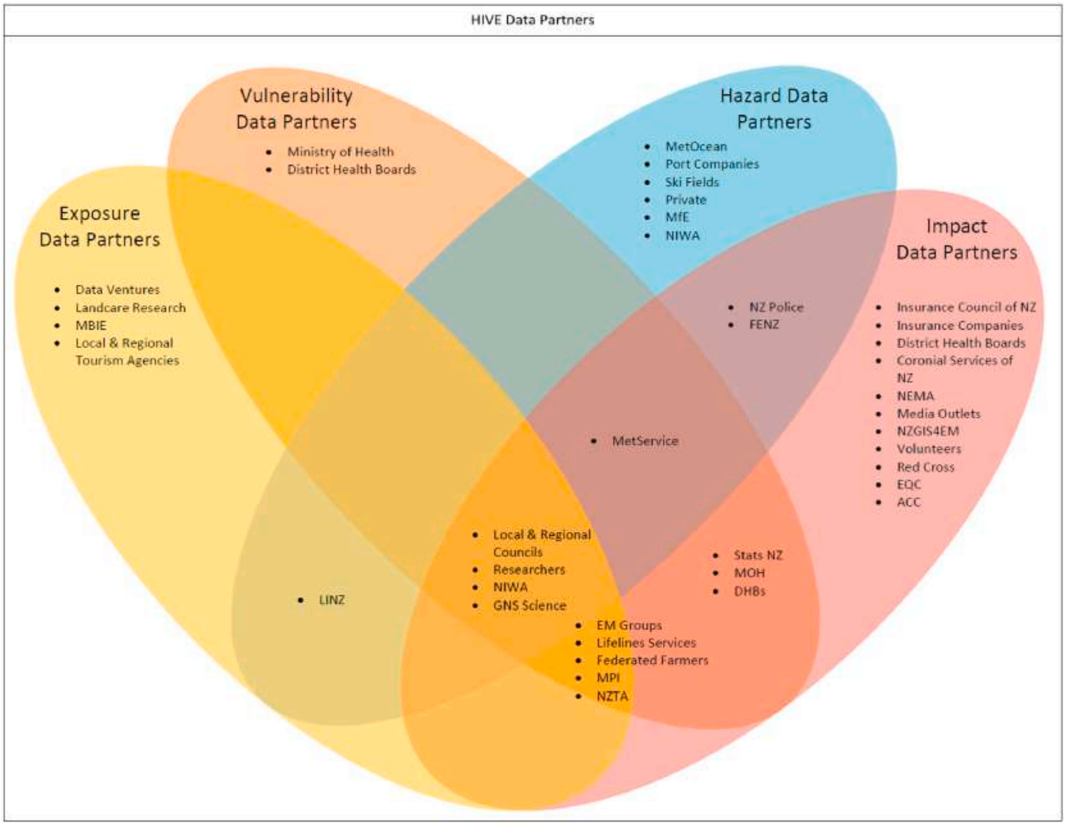


**Fig. 6.** A Venn diagram displaying agencies that possess HIVE data in Aotearoa New Zealand.

Zealand's national statistics agency), held exposure information in the form of cell phone location data. These data were used recently to inform decision-making around alert level changes in New Zealand in response to the COVID-19 pandemic [32]. There is potential for these data to be useful for risk and impact modelling for hydrometeorological hazards [32].

From the interviews, it appears that at least four groups in Aotearoa New Zealand possess all four types of data needed for IFWs. As shown in Fig. 6, based on the results presented by Harrison et al. [32], these are local and regional councils, university and independent researchers, and CRIs such as NIWA and GNS Science.

Local and regional councils possess data on flood hazards, such as river height and flow gauges, sea level data, river network, overland flow paths floodplain data, coastal inundation maps, slope data, and live camera feeds of river heights. In terms of impact data, some councils were found to use social media, crowdsourcing, and community volunteers to collect reports [32]. Councils also have their staff and contractors conduct damage assessments, and often write post-event reports after a significant event for post-event analysis. Councils possess data or information needed for vulnerability assessments, such as asset information (i.e., characteristics) and building damage assessments. Likewise, for exposure, councils have data on asset location and land-use zoning. Council staff possess tacit knowledge of hazard, impacts, vulnerability, and exposure, much of which is undocumented [32].

Researchers were also found to have various forms of HIVE data based on the interviews and workshops. Researchers often use social media and crowdsourcing to collect hazard and impact data for their own purposes [32]. Researchers indirectly collect data from media reports, and directly from damage surveys and post-event interviews/surveys [32]. Researchers also produce outputs from risk and impact models (e.g., Refs. [93–95]).

From the interviews and workshops, NIWA and GNS Science were the third and fourth agencies found to possess HIVE data in various forms for hydrometeorological hazards. Like the MetService, NIWA collects observational data for hydrometeorological hazards in addition to possessing data on river networks and sea levels in Aotearoa New Zealand. NIWA and GNS Science also conduct risk modelling for hydrometeorological and hydrogeological hazards using RiskScape, and thus collect and possess HIVE data for these assessments. For example, NIWA and GNS Science officials conduct damage surveys following heavy rainfall events to collect flood and landslide damage data respectively for buildings and produce exposure layers based on overlaying spatial asset and hazard layers [95,96]. At GNS Science, efforts are underway to build a Pacific region exposure dataset of buildings for use in risk models [93,94].

While one organisation might contain specific types of HIVE data (as shown in Fig. 6), they may not be useable for IFWs in isolation. For example, GNS Science has landslide hazard data but does not collect rainfall data, instead they obtain rainfall data from the MetService and NIWA. Thus, the distribution of HIVE data across the various agencies represented in Fig. 6 demonstrates the need to share data and knowledge between agencies for IFWs. This argument is supported in related IFW reports (e.g., Refs. [1,97]). The UK NHP is an example of how agencies share HIVE data to support IFWs. Findings from Harrison et al. [8] and Hemingway and Gunawan

[64] highlight how this formal partnership enables the UK MetOffice to obtain key information for their IFWs, such as transportation data from the UK transport authority, to inform their Vehicle OverTurning Model, or population movement (i.e., exposure data) from the UK Health and Safety Executive. Furthermore, as found by Harrison et al. [8], if an agency were to possess all of the required data for IFWs, the agency still cannot issue IFWs if that falls outside of its remit. Partnerships and collaboration thus are important for IFWs, to allow agencies with the required data for IFWs (such as NIWA, GNS Science, emergency management agencies) to work with the mandated warning services (such as the MetService and councils). Still, dynamic exposure and vulnerability, which have been identified as important for IFWs [8,98], were not found to be readily available in Aotearoa New Zealand.

#### 3.3.2. Re-defining warning thresholds

The informal partnerships that were found to exist between the MetService and Emergency Management agencies and hydrologists in Aotearoa New Zealand allow the MetService to (a) include Emergency Management agencies and hydrologists in their decision to issue a hazardous weather forecast, and (b) alert them to the fact that they have issued a hazardous forecast or warning so that they can prepare. They do this by ‘phoning up’ the hydrologists or Emergency Management agency to start the conversation, as shown in Fig. 7, and as reported by Harrison et al. [8].

Fig. 7 provides a conceptual example of a severe weather warning chain in Aotearoa New Zealand and the partners involved in this chain. This figure is the result of diagramming and memo-writing following interviews with the NZ MetService staff, Emergency Management agency officials, and hydrological experts within councils. Starting with monitoring hydrometeorological hazards by the MetService and council hydrologists, when a potentially hazardous hydrometeorological phenomenon is identified (such as heavy rainfall), the MetService reaches out to their hydrological and Emergency Management agency contacts in the region of interest to conduct a risk or impact assessment. This assessment can be discussion-based, model-based, or both [8].

Together the MetService and council may choose to issue a watch or warning and assign the appropriate warning colour (e.g., red or orange). For example, the MetService could issue an Orange or Red Warning based on feedback from the Emergency Management agency and hydrologist(s), considering antecedent conditions and long-term forecasted conditions [8]. The council would also be responsible for issuing a flood warning if needed [12]. The MetService also works with regions to adjust warning thresholds. For example, the MetService has worked with Auckland to adjust thresholds for damaging winds [8]. They also lower thresholds if they know the antecedent conditions might exacerbate the impacts by talking with the hydrologists and Emergency Management agencies to be aware of their current exposure, vulnerability, and response capacities [8]. This shows the importance of communicating and collaborating with stakeholders to define or redefine thresholds based on impacts for more effective warnings.

#### 3.3.3. Consistent warning messages

The consistency of warning messages is critical for effective risk communication [99]. Partnerships and Collaboration are important for ensuring that the warning messages and information are consistent across agencies and reaches target audiences. For this reason, Auckland Emergency Management works with the MetService to ensure the messages they release align with the forecasts and warnings from the MetService (Auckland Workshop). The MetService and a private weather forecasting company in Aotearoa Zealand have worked together over the years to strengthen their relationship to ensure that the messages they are releasing are productive for the public to act appropriately (Met. Private NZ. L). Alternatively, instances of conflicting weather forecasts have also occurred between hydrometeorological agencies in Aotearoa New Zealand where conflicting forecasts were posted on social media channels [100]. Having multiple providers of (sometimes conflicting) weather forecasts and warnings in the media (and social media) may cause public confusion, and lead to potential mistrust of the MetService and their role as the weather warning authority. As demonstrated by Smithson [101], receiving conflicting messages from multiple sources can raise suspicions about the trustworthiness or credibility of those sources. Further research should explore the impact of these multiple weather service providers on public judgement and warning related decision-making in Aotearoa New Zealand.

#### 3.3.4. Multi-hazard and cascading hazard warning messages

It is important to work towards multi-hazard EWSs that encapsulate cascading, coincident, and compounding hazards, as outlined in the Sendai Framework Priorities [102] and in the WMO IFW guidelines [1–3]. As summarised in Section 1, different agencies handle the monitoring, detection, forecasting, and warning of meteorological, hydrological volcanic, and tsunami hazards that present threats to society and the environment in Aotearoa New Zealand. While there is currently no established framework for a landslide EWS or earthquake EWS in Aotearoa New Zealand (although GNS Science is responsible for monitoring, identifying, and analysing both landslide and earthquake hazards [43]), researchers continue to investigate the feasibility of implementing landslide and earthquake EWSs in Aotearoa New Zealand [103–107].

Participants in this study emphasised the importance of taking an all hazards or multi-hazard approach for designing and implementing IFWs (Risk Modelling NZ. A; EM. NZ. Reg. D; EM. Gov. NZ. Nat. G; EM. Gov. NZ. Nat. J). This is because hazards rarely occur or produce impacts in isolation and it is important to consider how cascading, coincident, or compounding hazards produce impacts.

The warning chain shown in Fig. 7 provides one example where a meteorological phenomenon (rainfall) can produce a secondary hazard (flood), which can together produce various societal and environmental impacts. Similarly, heavy rainfall and floods can result in landslides, as demonstrated by recent large-scale heavy rainfall events and Cyclone Gabrielle that produced floods, hundreds to thousands of landslides, and fatalities in various parts of Aotearoa New Zealand 2023 [108,109]. Unrelated hazards can also occur at the same time and exacerbate impacts. For example, while ex-Tropical Cyclone Cody passed northeast of Aotearoa New Zealand and caused rough sea conditions from January 12-16, 2022 [110], the Hunga Tonga-Hunga Ha'apai volcanic eruption occurred on January 15, 2022 and produced a tsunami that hit parts of the Aotearoa New Zealand coastline [111,112]. These two concurrent events produced intense wave activity and subsequent impacts such as flooded campgrounds and damage to a marina and several boats

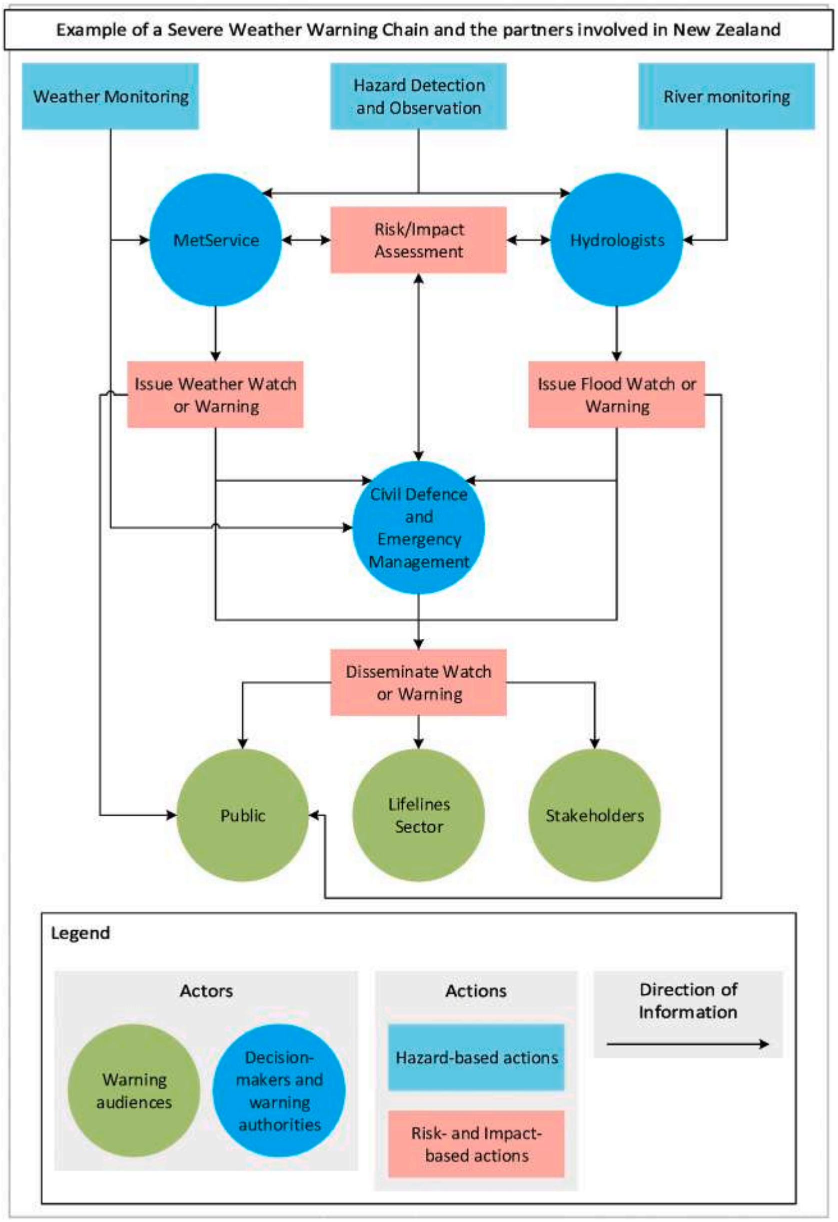


**Fig. 7.** A conceptual example of a severe weather warning chain in Aotearoa New Zealand and the partners involved. The figure identifies the actors (warning audiences and decision-makers and warning authorities) involved in the warning chain and their actions. The actions are either hazard-based (such as monitoring and collecting observational data of hazards) or risk- and impact-based (where risk and impacts are considered in addition to the hazard information). The direction of information and communication is represented by arrows. Multi-directional arrows indicate that the actors such as the MetService, hydrologists, and Emergency Management agencies both contribute to the risk assessments and are informed by the risk assessment outputs for their warning messages.

[113]. The need to consider these two hazards occurring simultaneously became evident when the authorities had to consider the most appropriate action advice for their warnings and advisories [114]. Given that responsibilities for warning of various hazards fall on different agencies in Aotearoa New Zealand, these agencies must continue to build and nurture strong relationships and communication networks to facilitate rapid data and knowledge exchange such that warnings contain accurate information about the impacts that may be produced from the multiple hazards interacting with, occurring alongside, or cascading after each other.

One regional emergency management official indicated that “[IFW] can be used for multi-hazards” (EM. NZ. Reg. D). One national emergency management participant described how

> “we've recently started some conversations … around … the options to bring together agencies from the emergency services … not around meteorological or natural hazard monitoring but more responding to hazards and risks in their spaces … There's an example of it in Christchurch with … the Christchurch Justice and Emergency Services Precinct, …it's police, fire and ambulance, the courts, NEMA. And it was created as a consequence of the [2011 Canterbury] earthquakes … so they had to rebuild

> and they said 'everybody's going to be in the same place, we'll have a common operations room and all the agencies will have their own separate things that they need, but when we come together for a thing that's a cross-agency response, we use this common space.' And I could imagine something [like that] with those natural hazard agencies. But it would need some … direction to be given by basically politically for that to happen because they're all managed in slightly different ways, as you know - boards and CRIs and funding and sources are all different" (EM. Gov. NZ. Nat. J).

This participant points to cohabitation, previously described, as a strategy for improving communication and enabling a more coordinated natural hazards response, including formulating multi-hazard early warnings and the need for top-down approaches to support this.

### *3.4. Partnerships and collaboration in the HIVE data phenomenon*

Due to the distribution of HIVE data sources across these agencies and stakeholders, as previously shown in Fig. 6, partnerships and collaboration are needed to increase accessibility to these datasets and data sources for IFWs and reduce instances of repetition for data collection and creation. Within the HIVE Data phenomenon of this study, partnerships and collaboration were found to affect data collection, data custodianship and management, and data access and sharing, as reported by Harrison et al. [15,32].

#### *3.4.1. Data collection*

Many agencies collect and create various forms of HIVE data for various uses [32]. Interdisciplinary or cross-disciplinary collaboration has become increasingly important for disaster-related data collection [60]. For example, Harrison et al. [8] found that to capture the social impacts of hydrometeorological hazards, risk modellers who typically conduct post-damage assessments to calibrate their models should coordinate and collaborate with social scientists to ensure that the templates capture appropriate characteristics to inform social impact models as well, and to ensure that the data collection method itself is ethically sound. Such interdisciplinary collaboration has the potential to incorporate new and shared perspectives to a problem [60]. Collaborators can thus jointly define and scope problems and identify the data types that are of interest to these problems [60]. The overall outcomes of this kind of 'data-driven' collaboration can be the production of "more holistic solutions that grow and evolve from the shared space" ([60], p. 1146). Successful collaborations typically have institutional support and a foundation of long-term collaborations [60].

#### *3.4.2. Data governance, access, and sharing*

Governance, access, and sharing of HIVE data also involve aspects of partnerships and collaboration. Data governance protocols help to establish authority and control over data by assigning clear roles and responsibilities [115]. Data governance also involves examining practices for data collection, management, accessibility, and use [116]. As reported by Harrison et al. [15], data governance became an important theme in discussions with participants about managing HIVE data. Furthermore, partnerships and collaboration were found to be important for agencies to learn from each other for best practices, particularly for agencies who have not traditionally collected such data in the past. For example, NEMA worked with Stats NZ to receive guidance on best practices for managing the national loss database currently in development for reporting under the Sendai Framework (see Ref. [15]). This example supports the notion that data governance depends on collaboration between the organisations and people of which the system comprises [116]. This includes establishing trusted frameworks for reliable and secure data sharing between organisations [116].

Partnerships and collaboration were found to enable access to and sharing of hydrometeorological HIVE data. The partnerships between the NZ MetService and Emergency Management agencies and hydrologists were outlined in the previous section to inform hydrometeorological warnings, as reported by Harrison et al. [32]. In addition to that, interviews indicated that the MetService shares their data files with hydrologists to integrate with their flood models [15]. Furthermore, the partnerships and collaboration formed in the GEMA community facilitates data sharing across agencies [15].

The MetService and a private weather forecasting company in Aotearoa New Zealand are co-developing amicable data access and sharing arrangements (Met. Private NZ. L). This is not necessarily the case with other agencies due to data sharing restrictions (Met. Private NZ. L). This has introduced a debate around which data should be made 'open' (Met. NZ. K). Global calls have been made to make hydrometeorological data openly accessible in a timely manner (e.g., in real time or near real time), citing various economic benefits (e.g., Ref. [117]). However, a review of open access to weather data in Aotearoa New Zealand conducted by MBIE [118] found that most data reuse principles are being met by the involved agencies, but access to observational weather data in Aotearoa New Zealand is more restricted than in other countries [118]. This is due to the State-Owned Enterprise and CRI models under which the agencies operate, which are based on earning commercial revenue to support data collection and cover operating costs [118]. MBIE [118] concluded that the costs to the taxpayers of increasing open access to raw observation data would outweigh the benefits.

While the MBIE [118] review determined that the current accessibility of weather-related data is acceptable when considering the cost-benefit to taxpayers, this issue highlights the importance of forming functional partnerships such that data sharing agreements can be made between agencies [119]. The Weather Enterprise in the USA is an example of a public-private-academic partnership formed across the various sectors involved in collecting, creating, using, and communicating weather information (e.g., Government agencies, emergency management agencies, academia, private agencies, broadcast media, social science) ([120].). The Global Weather Enterprise (GWE) is another example of efforts towards increasing the accessibility of weather information [121]. The GWE comprises all the EWS components, products, processes, and actors that must come together to provide accurate and reliable weather information [121]. As the GWE is collaborative in nature, partnerships across culturally different sectors are essential to its success [121].

## 4. Discussion and conclusion

There are global efforts to design and implement IFWs to better communicate the anticipated outcomes, consequences, or impacts of the hazard with more context around vulnerability and exposure. This paper is part of a larger project that investigated the data needs and data sources for implementing an IFW system in Aotearoa New Zealand (e.g., Refs. [3,8,14,15]). Partnerships and collaboration emerged as a critical component to facilitating data access for implementing IFWs, and in this paper we drew lessons from across this work to demonstrate the importance of partnerships for IFW systems.

The relationship of Partnerships and Collaboration with the two phenomena in this study (IFWs and HIVE Data) is represented in Fig. 5. Sharing knowledge and data is the crucial interface between IFWs and HIVE Data because it helps to fill the knowledge and data gap identified by meteorologists in practice and that identified from the literature for implementing IFWs (e.g., Ref. [12]). Findings from Harrison et al. [8] showed the needs for HIVE data throughout the warning process for IFWs, such as the need for dynamic exposure and vulnerability information to set thresholds for impact warnings and account for changes in population movement. Additional findings from Harrison et al. [32] identified existing and potential sources for HIVE data that can support IFWs, such as tacit knowledge, damage surveys, social media, crowdsourcing, wellbeing surveys, and insurance claims. However, because the data sources are numerous with many actors involved in their collection and use, the need for effectively managing, sharing, and accessing the data was identified and further explored by Harrison et al. [15]. Thus, it was found that Partnerships and Collaboration are essential for facilitating effective data sharing practices for IFW implementation.

The findings of this study that point to Partnerships and Collaboration as a necessary strategy for implementing IFWs align with recommendations in the WMO Guidelines [1,3] and a guide on impact-based forecasting published by the International Federation of Red Cross and Red Crescent Societies (IFRC; [97]). Partnerships enable organisations to understand hazards, identify impacts, and assess user requirements [97]. The UK's NHP was lauded for “leading the way in moving from hazard-based to impact-based natural hazard research to better understand and forecast potential impacts” ([64], p. 508). Such a partnership allows for including diverse scientific expertise that promotes efficient, robust, and “practically relevant” forecasting tools ([64], p. 508). This current study provides further empirical evidence from the Aotearoa New Zealand context of the need for building and nurturing partnerships and collaboration both for implementing IFWs and for better management of, and access to, HIVE data for IFWs and DRR in general. This contributes to the need identified by Kox and Lüder [11] for international cross-analysis of the meanings of impact weather-related challenges and communication procedures.

Multi-organisational collaboration has many challenges [122]. The process of building partnerships requires extensive time, coordination, communication, and interaction between agencies [64]. Barriers to these factors include resourcing, such as available funding for billable hours, workloads, and establishing roles. Building trust and increasing the willingness of individuals and organisations to participate are additional hurdles [122,123], particularly in organisations or roles where staff turnover may be high (a particular challenge in organisations where staff frequently move between teams or experience burnout and leave the sector). Further challenges include mutually identifying goals and objectives and agreeing on timelines, the use of differing terminology and epistemologies, legal issues around intellectual property and data access, developing workflows and communication standards, and sustaining the collaboration [122,123].

Additionally, individual psychological and behavioural factors can also impede or enable the formation and sustainability of relationships and collaboration. Such factors include, and are not limited to, needs, biases, mood, motivation, preferences, personality, culture, ambitions, attention and memory, and working style as summarised by Patel, Pettitt and Wilson [124]. These factors, combined with other factors such as organisational structure, can shape the organisational culture and its openness and capacity to enter into partnerships and collaborations [124].

Finally, developing partnerships to share data between agencies for an IFW system is based on the initial assumption that agencies that possess the desired data are both willing and able to share these data. Legal and ethical policies and frameworks may prevent the ability to openly share certain datasets (e.g., Ref. [125–127]). Indeed, data privacy laws have impeded the sharing of data between public service and public safety agencies [125]. Lips et al. [125] noted that agencies in Aotearoa New Zealand operating under a public safety mandate are less restricted to information sharing than those operating under the public service mandate. Co-location and information sharing protocols were further identified as enablers to inter-agency information sharing, whereby co-location was observed to facilitate trust-building and information co-creation and sharing, and information sharing protocols allowed staff from other agencies to be treated as “honorary employees” with unrestricted access to the information and data ([125], p. 263). Most recently, the Data Privacy Act prevented the sharing and use of sensitive data for responding to and mitigating the spread of COVID-19 in Aotearoa New Zealand [126]. Consequently, there is a call for debate about the use of data in disaster events in Aotearoa New Zealand [126]. The discussions and legislation would provide a regulatory framework about the appropriate and ethical collection and sharing of data for disaster response and collective public safety, and the deletion of data after an event [126].

When considering sharing of non-sensitive data (e.g., data that are not collected from or about individuals), open access data policies exist to facilitate open and free access to other datasets, such as weather and other hazard monitoring data. However, the current restricted access to weather data in Aotearoa New Zealand prevents the voluntary provision of open weather data.

Similar to the influencing factors of collaboration and partnerships, as summarised by Patel, Pettitt and Wilson [124], an agency's values are likely to influence their approach to open access data in the absence of a more ‘open’ data access policy. For example, in Aotearoa New Zealand, GeoNet (a partnership between GNS Science, EQC, LINZ, NEMA, and MBIE) collects and distributes geohazard data which they make freely available to the public to support hazard and risk management and research [128]. It is likely that, in addition to the funding structure of the GeoNet partnership, the values of these agencies involved in the GeoNet partnership towards open data access align and thus directly support the open and free access to these datasets.

The findings of this study build on existing recommendations from the international literature to increase interagency communication and partnerships for IFWs and DRR (e.g., Refs. [3,11,97]) by providing more tangible and direct strategies. For example:

- Meteorologists can **directly communicate with the emergency services** in question, as is done in Aotearoa New Zealand using telephone and email. A mailing list or stream of meteorological forecasts and warnings can be made available for emergency responders to loop into and choose to escalate according to their own situation. Simple and direct communication systems can help with the rapid exchange of information and knowledge in high pressure times, as was proven during the 2012 Tongariro eruption crisis in Aotearoa New Zealand where email and telephone communication lines were rapidly established to facilitate communication between key response agencies [69].
- The meteorological service and emergency responders can **work together to define tailored warning thresholds.** For example, the meteorological service can adjust thresholds for a particular area, hazard, or event based on feedback from emergency management agencies who are knowledgeable about their communities' exposure and vulnerability and have experienced or observed the impacts directly. For example, the Aotearoa New Zealand MetService adjusted the severe wind threshold for Auckland due to its vulnerability to northeasterly winds [8]. In the USA, the National Weather Service changed the criterion for severe hail based on empirical research and feedback from emergency management agencies [129].
- The meteorological service, emergency responders, and other stakeholders can **make cohabitation arrangements and run joint training scenarios** together to facilitate visits, and identify needs, or fill gaps in communication. This builds trust between agencies, and helps with mutually identifying goals, clarifying terminologies and epistemologies, and sustaining the collaboration [130]. However, in a combined digital and post-pandemic era following Covid-19, remote working arrangements have increased in practice. Therefore, co-location arrangements should allow for flexibility and the leveraging of new technology to allow for remote collaboration and coordination. One example is to create multi-agency channels on Microsoft Teams, Slack, or similar software tools.
- Attending conferences across sectors **facilitates networking** and scoping initial interest and capabilities in building partnerships and collaboration. The results of the networking exercise may then be brought to policymakers and decisionmakers to implement a more top-down approach for mandating formal partnerships which may then open funding opportunities to support these efforts and provide guidance on legal issues with data sharing.

While the qualitative nature of data collection and analysis herein limits the generalisability of results beyond the participants, this approach offers in-depth understanding of a problem not readily available from quantitative approaches, appropriate for an exploratory study such as this [131–133]. Furthermore, the purpose of theory-building in GTM is not to generalise, but to generate a theory with the most explanatory power for a particular set of data [134]. The results of this study are grounded in the experience and knowledge of the participants of this study in a specific time and place [58]. To increase the generalisability of these results beyond the participants and beyond the context of Aotearoa New Zealand, future research can be conducted to test the concepts developed in this research to a study in another area and/or amongst a different set of participants [135].

The response to the COVID-19 pandemic interfered with the data collection efforts for this study. As such, several key informants were unable to participate in this study due to their involvement in the COVID-19 response, such as Emergency Management practitioners well-versed in the collection and management of Wellbeing and Welfare data. Interview and workshop methods had to be adaptable to the dynamic conditions posed by the COVID-19 risks and response. While in-person interviews and workshops were preferred to facilitate high quality data collection this was not always possible. This created an opportunity to experiment with novel workshop data collection methods, such as the online whiteboard platform Mural. The results of these workshops revealed both strengths and weaknesses of running virtual workshops. Some notable strengths to using a virtual whiteboard to facilitate virtual workshops and to capture data are the lack of additional administrative work required to document and store the resulting data (e.g., there was no need to take photos of sticky notes before packing up the sticky notes, sheets of paper, pens and other workshop materials), the flexibility to design and customise the virtual whiteboard as desired and unrestricted by paper size, and the ability for all participants to remotely interact and participate individually during breakout sessions. However, some of these benefits were only observed when each participant joined remotely from their own computers. In one workshop, we did not anticipate that the participants would coordinate with each other and join online from the same meeting room such that the facilitator/researcher was the only person joining virtually. This made it difficult to record each participants' responses onto virtual sticky notes as the participants had to share the keyboard until one person was anointed scribe to record the responses. While this resulted in less detailed response on the virtual whiteboard, the discussion was found to be richer than that from the other workshops where each participant joined on their own computer. This experience points to further opportunities for learning from and planning future virtual data collection methods, such as to investigate impact forecasting and warning collaborations across distributed global teams.

## CRediT authorship contribution statement

**Sara E. Harrison:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Sally H. Potter:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. **Raj Prasanna:** Methodology, Project administration, Supervision, Writing – review & editing. **Emma E.H. Doyle:** Supervision, Writing – review & editing. **David Johnston:** Funding acquisition, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The authors do not have permission to share data.

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## References

[1] WMO, WMO Guidelines on Multi-Hazard Impact-Based Forecast and Warning Services (9789263111500), 2015. https://www.wmo.int/pages/prog/www/DPFS/Meetings/ET-OWFPS_Montreal2016/documents/WMOGuidelinesonMulti-hazardImpact-basedForecastandWarningServices.pdf.
[2] WMO, Multi-hazard early warning systems: a checklist, in: The First Multi-hazard Early Warning Conference, Cancun, Mexico, 2018.
[3] WMO, WMO Guidelines on Multi-Hazard Impact-Based Forecast and Warning Services Part II: Putting Multi-Hazard IBFWS into Practice, 2021. https://library.wmo.int/doc_num.php?explnum_id=10936.
[4] R. Basher, Global early warning systems for natural hazards: systematic and people-centred, Philosoph. Trans. Royal Soc. 364 (1845) (2006) 2167–2182, https://doi.org/10.1098/rsta.2006.1819.
[5] P.K. Ching, V. Carr de los Reyes, M.N. Sucaldito, E. Tayag, An assessment of disaster-related mortality post-Haiyan in Tacloban City, Western Pacific Surveill. Response J. 6 (2015) 34–38, https://doi.org/10.5365/WPSAR.2015.6.2.HYN_005.
[6] Q. Zhang, C.-P. Ng, K. Dai, J. Xu, J. Tang, J. Sun, M. Mu, Lessons learned from the tragedy during the 100 km ultramarathon race in Baiyin, Gansu Province on 22 may 2021, Adv. Atmospheric Sci. (2021), https://doi.org/10.1007/s00376-021-1246-0.
[7] R. Wagenmaker, J. Weaver, G. Garnet, B. Perry, J. Spinner, G. Mann, NWS Central Region Service Assessment Joplin, Missouri, Tornado – May 22, 2011, https://www.weather.gov/media/publications/assessments/Joplin_tornado.pdf, 2011.
[8] S.E. Harrison, S.H. Potter, R. Prasanna, E.E.H. Doyle, D.M. Johnston, Identifying the data uses and gaps for severe weather impact forecasts and warnings, Weather Clim. Soc. (2022), https://doi.org/10.1175/WCAS-D-21-0093.1.
[9] R. Kaltenberger, A. Schaffhauser, M. Staudinger, "What the weather will do" – results of a survey on impact-oriented and impact-based warnings in European NMHSs, Adv. Sci. Res. 17 (2020) 29–38, https://doi.org/10.5194/asr-17-29-2020.
[10] T. Kox, H. Kempf, C. Lüder, R. Hagedorn, L. Gerhold, Towards user-orientated weather warnings, Int. J. Disaster Risk Reduc. 30 (February) (2018) 74–80, https://doi.org/10.1016/j.ijdrr.2018.02.033.
[11] T. Kox, C. Lüder, Impacts as triggers for weather-related decision making: observations at the Berlin fire brigade control and dispatch center, Int. J. Disaster Risk Sci. (2021), https://doi.org/10.1007/s13753-021-00356-4.
[12] S.H. Potter, S.E. Harrison, P. Kreft, The benefits and challenges of implementing impact-based severe weather warning systems: perspectives of weather, flood, and emergency management personnel, Weather Clim. Soc. 13 (2) (2021) 303–314, https://doi.org/10.1175/wcas-d-20-0110.1.
[13] T. Kox, C. Lüder, L. Gerhold, Anticipation and response: emergency services in severe weather situations in Germany, Int. J. Disaster Risk Sci. 9 (2018) 116–128, https://doi.org/10.1007/s13753-018-0163-z.
[14] S.E. Harrison, S.H. Potter, R. Prasanna, E.E.H. Doyle, D.M. Johnston, Volunteered Geographic Information for people-centred severe weather early warning: a literature review, Australas. J. Disaster Trauma Stud. 24 (1) (2020). http://trauma.massey.ac.nz/issues/2020-1/AJDTS_24_1_Harrison.pdf.
[15] S.E. Harrison, S.H. Potter, R. Prasanna, E.E.H. Doyle, D.M. Johnston, 'Sharing is caring': a socio-technical analysis of the sharing and governing of hydrometeorological hazard, impact, vulnerability, and exposure data in Aotearoa New Zealand, Progress Disaster Sci. (2022), https://doi.org/10.1016/j.pdisas.2021.100213.
[16] M. Spruce, R. Arthur, J. Robbins, H.T.P. Williams, Social sensing of high-impact rainfall events worldwide: a benchmark comparison against manually curated impact observations, Nat. Hazards Earth Syst. Sci. (2021), https://doi.org/10.5194/nhess-2020-413.
[17] M. Spruce, R. Arthur, H.T.P.T.P. Williams, Using social media to measure impacts of named storm events in the United Kingdom and Ireland, Meteorol. Appl. 27 (1) (2020) 1–17, https://doi.org/10.1002/met.1887.
[18] R. Hemingway, J. Robbins, Developing a hazard-impact model to support impact-based forecasts and warnings: the Vehicle OverTurning (VOT) Model, Meteorol. Appl. (2019) 1–17 https://doi.org/10.1002/met.1819, April.
[19] J. Hofmann, H. Schüttrumpf, Risk-based early warning system for pluvial flash floods: approaches and foundations, Geosciences 9 (3) (2019), https://doi.org/10.3390/geosciences9030127.
[20] D. Mu, T.R. Kaplan, R. Dankers, Decision making with risk-based weather warnings, Int. J. Disaster Risk Reduc. 30 (2018) 59–73, https://doi.org/10.1016/j.ijdrr.2018.03.030.
[21] R.A. Neal, P. Boyle, N. Grahame, K. Mylne, M. Sharpe, Ensemble based first guess support towards a risk-based severe weather warning service, Meteorol. Appl. 21 (3) (2014) 563–577, https://doi.org/10.1002/met.1377.
[22] J.C. Robbins, H.A. Titley, Evaluating high-impact precipitation forecasts from the met office global hazard map using a global impact database, Meteorol. Appl. (2018) 548–560 https://doi.org/10.1002/met.1720, July 2017.
[23] L. Wei, J. Li, X. Yang, Experiments on impact-based forecasting and risk-based warning of typhoon in China, Trop. Cycl. Res. Rev. (2018) 31–36, https://doi.org/10.6057/2018TCRR01.04.
[24] R.E. Morss, J.L. Demuth, J.K. Lazo, K. Dickinson, H. Lazrus, B.H. Morrow, Understanding public hurricane evacuation decisions and responses to forecast and warning messages, Weather Forecast. 31 (2) (2016) 395–417, https://doi.org/10.1175/WAF-D-15-0066.1.
[25] M.F. Perreault, J.B. Houston, L. Wilkins, Does scary matter?: testing the effectiveness of new national weather service tornado warning messages, Commun. Stud. (2014), https://doi.org/10.1080/10510974.2014.956942.
[26] S.H. Potter, P. Kreft, P. Milojev, C. Noble, B. Montz, A. Dhellemmes, R.J. Woods, S. Gauden-Ing, The influence of impact-based severe weather warnings on risk perceptions and intended protective actions, Int. J. Disaster Risk Reduc. 30 (March) (2018) 34–43, https://doi.org/10.1016/j.ijdrr.2018.03.031.
[27] A.L. Taylor, A. Kause, B. Summers, M. Harrowsmith, Preparing for Doris: exploring public responses to impact-based weather warnings in the United Kingdom, Weather Clim. Soc. 11 (4) (2019) 713–729, https://doi.org/10.1175/WCAS-D-18-0132.1.
[28] P. Weyrich, A. Scolobig, D.N. Bresch, A. Patt, Effects of impact-based warnings and behavioural recommendations for extreme weather events, Weather Clim. Soc. 10 (2018) 781–796, https://doi.org/10.1175/WCAS-D-18-0038.1.
[29] P. Weyrich, A. Scolobig, A. Patt, Dealing with inconsistent weather warnings: effects on warning quality and intended actions, Meteorol. Appl. 26 (4) (2019) 569–583, https://doi.org/10.1002/met.1785.

[30] P. Weyrich, A. Scolobig, F. Walther, A. Patt, Do intentions indicate actual behaviour? A comparison between scenario-based experiments and real-time observations of warning response, J. Contingencies Crisis Manag. 28 (3) (2020) 240–250, https://doi.org/10.1111/1468-5973.12318.
[31] P. Weyrich, A. Scolobig, F. Walther, A. Patt, Responses to severe weather warnings and affective decision-making, Nat. Hazards Earth Syst. Sci. 20 (10) (2020) 2811–2821, https://doi.org/10.5194/nhess-20-2811-2020.
[32] S.E. Harrison, S.H. Potter, R. Prasanna, E.E.H. Doyle, D.M. Johnston, 'Where oh where is the data?': identifying data sources for hydrometeorological impact forecasts and warnings in Aotearoa New Zealand, Int. J. Disaster Risk Reduc. (2021), https://doi.org/10.1016/j.ijdrr.2021.102619.
[33] D. Paton, E. Anderson, J. Becker, L. Petersen, Understanding Functional Earthquake Readiness: Development and Preliminary Validation of Earthquake Readiness Measures and Predictors, 2015.
[34] D. Paton, L. Mamula-Seadon, K.L. Selway, Community Resilience in Christchurch: Adaptive Responses and Capacities during Earthquake Recovery, 2013.
[35] C. Garcia, C.J. Fearnley, Evaluating critical links in early warning systems for natural hazards, Environ. Hazards 11 (2) (2012) 123–137, https://doi.org/10.1080/17477891.2011.609877.
[36] M. Williamson, Meteorological Service Contract, New Zealand Government, Wellington, New Zealand, 1998 Retrieved from. https://www.beehive.govt.nz/feature/meteorological-service-contract.
[37] Ministry for the Environment, Flooding – Roles and Responsibilities, 2016 Retrieved 16 March from. https://www.mfe.govt.nz/more/natural-hazard-management/flood-risk-management/roles-and-responsibilites.
[38] S.M. Cullen, K. Christensen, C. Price, Rangitāiki River Scheme Review – April 2017 Flood Event, 2017. https://www.boprc.govt.nz/media/773858/rangitaiki-river-scheme-review-april-2017-flood-event-final-report-as-supplied-to-by-of-plenty-regional-council.pdf.
[39] Ministry for the Environment, & The Flood Risk Management and River Control Review Steering Group, Meeting the Challenges of Future Flooding in New Zealand, 2008.
[40] H. Rouse, Flood risk management research in New Zealand Where are we, and where are we going? (2012/04), GNS Science, 2011.
[41] K. Charmaz, Constructing Grounded Theory, SAGE Publications Ltd, 2006.
[42] New Zealand Government, The Guide to the National Civil Defence Emergency Management Plan 2015, Department of the Prime Minister and Cabinet, Wellington, NZ, 2015 Retrieved from. https://www.civildefence.govt.nz/assets/guide-to-the-national-cdem-plan/Guide-to-the-National-CDEM-Plan-2015.pdf.
[43] Civil Defence Emergency Management Amendment Act 2016, 2016. https://www.legislation.govt.nz/act/public/2016/0088/latest/DLM6648809.html?src=qs.
[44] B. Golding, Towards the Perfect Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication, Springer Cham, 2022, https://doi.org/10.1007/978-3-030-98989-7.
[45] J. Corbin, A. Strauss, in: V. Knight, Y. McDuffee, L. Barrett, M. Markanich (Eds.), Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, fourth ed., SAGE Publications Inc, 2015.
[46] B. Glaser, A. Strauss, The Discovery of Grounded Theory: Strategies for Qualitative Research, Aldine Publishing Company, 1967.
[47] J. Corbin, A. Strauss, Grounded theory research: procedures, canons, and evaluative criteria, Qual. Sociol. 13 (1) (1990) 3–21, https://doi.org/10.1007/BF00988593.
[48] A.L. Strauss, J.M. Corbin, Basics of Qualitative Research: Grounded Theory Procedures and Techniques, Sage Publications, 1990.
[49] K.L. Rieger, Discriminating among grounded theory approaches, Nurs. Inq. 26 (1) (2019) 1–12, https://doi.org/10.1111/nin.12261.
[50] Y. Chun Tie, M. Birks, K. Francis, Grounded theory research: a design framework for novice researchers, SAGE Open Med. 7 (2019) 1–8, https://doi.org/10.1177/2050312118822927.
[51] B. Gibson, Accommodating critical theory, in: A. Bryant, K. Charmaz (Eds.), The SAGE Handbook of Grounded Theory, SAGE Publications Ltd, 2007, pp. 436–454.
[52] GNS Science (n.d.). Our Science - Natural Hazards and Risks. Retrieved 1 June 2021 from https://www.gns.cri.nz/Home/Our-Science/Natural-Hazards-and-Risks.
[53] R.J. Woods, S.K. McBride, L.M. Wotherspoon, S. Beavan, S.H. Potter, D.M. Johnston, T.M. Wilson, D. Brunsdon, E.S. Grace, H. Brackley, J.S. Becker, Science to emergency management response: kaikōura Earthquakes 2016, Bull. N. Z. Soc. Earthq. Eng. 50 (2) (2017) 329–337, https://doi.org/10.5459/bnzsee.50.2.329-337.
[54] M. Bergin, NVivo 8 and consistency in data analysis: reflecting on the use of a qualitative data analysis program, Nurse Res. 18 (3) (2011) 6–12, https://doi.org/10.7748/nr2011.04.18.3.6.c8457.
[55] M. Vollstedt, S. Rezat, An introduction to grounded theory with a special focus on axial coding and the coding paradigm, in: G. Kaiser, N. Presmeg (Eds.), Compendium for Early Career Researchers in Mathematics Education, Springer International Publishing, 2019, pp. 81–100, https://doi.org/10.1007/978-3-030-15636-7_4.
[56] V. Timonen, G. Foley, C. Conlon, Challenges when using grounded theory: a pragmatic introduction to doing GT research, Int. J. Qual. Methods 17 (1) (2018) 1–10, https://doi.org/10.1177/1609406918758086.
[57] C. Urquhart, H. Lehmann, M.D. Myers, Putting the 'theory' back into grounded theory: guidelines for grounded theory studies in information systems, Inf. Syst. J. 20 (4) (2010) 357–381, https://doi.org/10.1111/j.1365-2575.2009.00328.x.
[58] F. Alammar, *Business Diplomacy In Practice: A Grounded Theory Study In Management Among Professional Diplomats* [Doctor of Philosophy, Massey University, Auckland, New Zealand, 2018.
[59] C. Urquhart, Scaling up the theory, in: Grounded Theory for Qualitative Research: A Practical Guide, 2013, pp. 129–147, https://doi.org/10.4135/9781526402196.n7.
[60] Y.G. Ge, C.W. Zobel, P. Murray-Tuite, R. Nateghi, H. Wang, Building an interdisciplinary team for disaster response research: a data-driven approach, Risk Anal. 41 (7) (2021) 1145–1151, https://doi.org/10.1111/risa.13280.
[61] D.R. Johnson, Integrated risk assessment and management methods are necessary for effective implementation of natural hazards policy, Risk Anal. 41 (7) (2021) 1240–1247, https://doi.org/10.1111/risa.13268.
[62] R.E. Morss, H. Lazrus, J.L. Demuth, The "inter" within interdisciplinary research: strategies for building integration across fields, Risk Anal. 41 (7) (2021) 1152–1161, https://doi.org/10.1111/risa.13246.
[63] L. Peek, J. Tobin, J.W. van de Lindt, A. Andrews, Getting interdisciplinary teams into the field: institutional review board preapproval and multi-institution authorization agreements for rapid response disaster research, Risk Anal. 41 (7) (2021) 1204–1212, https://doi.org/10.1111/risa.13740.
[64] R. Hemingway, O. Gunawan, The Natural Hazards Partnership: a public-sector collaboration across the UK for natural hazard disaster risk reduction, Int. J. Disaster Risk Reduc. (2018) 499–511, https://doi.org/10.1016/j.ijdrr.2017.11.014.
[65] Cabinet Office, The Pitt Review: Learning Lessons from the 2007 Floods - Full Report, 2008 UK Retrieved from. http://archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html.
[66] NEMA, New Zealand Volcanic Science Advisory Panel (NZVSAP) Terms of Reference, 2020 Retrieved from. https://www.civildefence.govt.nz/assets/Uploads/publications/nzvsap-tor-sep-2020.pdf.
[67] S. Bayley, Living with Volcanoes: the Taranaki Story, 2004 *Tephra, 21*. https://www.civildefence.govt.nz/assets/Uploads/publications/tephra-september-2004.pdf.
[68] E.E.-H. Doyle, D. Paton, D.M. Johnston, Enhancing scientific response in a crisis: evidence-based approaches from emergency management in New Zealand, J. Appl. Volcanol. 4 (1) (2015), https://doi.org/10.1186/s13617-014-0020-8.
[69] G.S. Leonard, C. Stewart, T.M. Wilson, J.N. Procter, B.J. Scott, H.J. Keys, G.E. Jolly, J.B. Wardman, S.J. Cronin, S.K. McBride, Integrating multidisciplinary science, modelling and impact data into evolving, syn-event volcanic hazard mapping and communication: a case study from the 2012 Tongariro eruption crisis, New Zealand, J. Volcanol. Geoth. Res. 286 (2014) 208–232, https://doi.org/10.1016/j.jvolgeores.2014.08.018.
[70] MBIE. . Resilience to Nature's challenges | Kia manawaroa - Ngā Ākina o Te Ao Tūroa. (n.d.) Retrieved 21 July 2021 from https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/investment-funds/national-science-challenges/the-11-challenges/resilience-to-natures-challenges/.

[71] Natural Hazards Research Platform, NHRP - About Us, 2020 Retrieved 21 July 2021 from. https://www.naturalhazards.org.nz/NHRP/About-Us.
[72] RNC, The Resilience Challenge, 2018 Retrieved. https://resiliencechallenge.nz/. (Accessed 21 July 2021).
[73] K. Jung, M. Song, H.J. Park, The dynamics of an interorganizational emergency management network: interdependent and independent risk hypotheses, Publ. Adm. Rev. 79 (2) (2018) 225–235, https://doi.org/10.1111/puar.12993.
[74] J. Olmos-Penuela, J. Molas-Gallart, E. Castro-Martinez, Informal collaborations between social sciences and humanities researchers and non-academic partners, Sci. Publ. Pol. 41 (4) (2013) 493–506, https://doi.org/10.1093/scipol/sct075.
[75] N. Kapucu, F. Demiroz, Interorganizational networks in disaster management, in: E.C. Jones, A.J. Faas (Eds.), Social Network Analysis of Disaster Response, Recovery, and Adaptation, Butterworth-Heinemann, 2017, pp. 25–39, https://doi.org/10.1016/B978-0-12-805196-2.00003-0.
[76] GEMA, Cyclone Gabrielle GIS Story - How Geospatial Helped Suppot the Gabrielle Response, 2023 Retrieved 8 March 2024 from. https://storymaps.arcgis.com/stories/b51c6b5ba14d4ea18fc8350580983fe5.
[77] E.E.-H. Doyle, J.S. Becker, D.P. Neely, D.M. Johnston, B. Pepperell, Knowledge transfer between communities, practitioners, and researchers: a case study for community resilience in Wellington, New Zealand, Australas. J. Disaster Trauma Stud. 19 (2) (2015) 55–66. https://trauma.massey.ac.nz/issues/2015-2/AJDTS_19_2_Doyle.pdf.
[78] J.E. Rovins, E.E.-H. Doyle, T.J. Huggins, 2?? Integrated research on disaster risk conference - integrated disaster risk science: a tool for sustainability, Planet. Rep. 2 (5) (2014). https://www.irdrinternational.org/knowledge_pool/publications/230.
[79] K.M. Gustafsson, R. Lidskog, Boundary organizations and environmental governance: performance, institutional design, and conceptual development, Climate Risk Manag. 19 (2018) 1–11, https://doi.org/10.1016/j.crm.2017.11.001.
[80] E.E.-H. Doyle, D. Paton, Decision-making: preventing miscommunication and creating shared meaning between stakeholders, in: Observing the Volcano World, 2017, pp. 549–570, https://doi.org/10.1007/11157_2016_31.
[81] H.R. Hosterman, J.K. Lazo, J.M. Sprague-Hilderbrand, J.E. Adkins, Using the National Weather Service's impact-based decision support services to prepare for extreme winter storms, J. Emerg. Manag. 17 (6) (2019) 455–467, https://doi.org/10.5055/jem.2019.0439.
[82] A. Wein, S.H. Potter, S. Johal, E.E. Doyle, J.S. Becker, Communicating with the public during an earthquake sequence: improving communication of geoscience by coordinating roles, Seismol Res. Lett. 87 (1) (2016).
[83] Flood Forecasting Centre (n.d.). Welcome to the Flood Forecasting Centre. Retrieved 22 July 2021 from http://www.ffc-environment-agency.metoffice.gov.uk/.
[84] J. Henderson, E.R. Nielsen, G.R. Herman, R.S. Schumacher, A hazard multiple: overlapping tornado and flash flood warnings in a national weather service forecast office in the southeastern United States, Weather Forecast. 35 (4) (2020) 1459–1481, https://doi.org/10.1175/WAF-D-19-0216.1.
[85] C. Pilling, New developments at the Flood Forecasting Centre: operations and flood risk guidance, in: D. Proverbs, S. Mambretti, C.A. Brebbia, N. Ursino (Eds.), Urban Water Systems & Floods, vol. 165, WIT Press, 2016, https://doi.org/10.2495/UW160211.
[86] M. Campbell, Can Precinct Planning Assist in the Reactivation of Urban Cores? Lessons from Ōtautahi-Christchurch, 2022 [Masters Thesis, University of Otago]. Otago, New Zealand. http://hdl.handle.net/10523/12769.
[87] M. Edwards, Social science research and public policy: narrowing the divide, Aust. J. Publ. Adm. 64 (1) (2005) 68–74, https://doi.org/10.1111/j.1467-8500.2005.00417.x.
[88] G. Kass, A.M. Milner, K. Dodds, The "borderlands" of the science–policy interface, Geogr. J. (2022), https://doi.org/10.1111/geoj.12469.
[89] A. Tasker, L.C. Irvine, Embedded social science and the British government COVID-19 response, Anthropol. Action 29 (1) (2022) 60–68, https://doi.org/10.3167/aia.2022.290107.
[90] Toka Tū Ake EQC, New Chief Engineer Role Connects Policy, Research, Engineering Practice, 2022 Retrieved. https://www.eqc.govt.nz/news/new-chief-engineer-role-connects-policy-research-engineering-practice/. (Accessed 12 September 2022).
[91] PMCSA, *Chief Science Advisor Forum He Rauhinga Tohu Putaiao*. Office of the Prime Minster's Chief Science Advisor, 2022 Retrieved 12 September 2022 from.
[92] Massey University, New Partnership between Joint Centre for Disaster Research and Earthquake Commission, 2021 Retrieved 12 September 2022 from. https://livenews.co.nz/2021/12/09/new-partnership-between-joint-centre-for-disaster-research-and-earthquake-commission/.
[93] S.L. Lin, A.B. King, I. Matcham, Exposure Data Development Framework: Real-Time Individual Asset Attribute Collection Tool (RiACT), in: Inventory Repository & Asset Repository Web Portal 2014 NZSEE Conference, Auckland, NZ, 2014.
[94] S.L. Lin, J. Ungaro, J.T. Nimau, S. Singh, K. Raqisia, Development of pacific exposure dataset for use in catastrophe risk assessment. Natural Hazards, 2020, https://doi.org/10.1007/s11069-020-04290-4.
[95] R. Paulik, S. Stephens, R. Bell, S. Wadhwa, B. Popovich, National-scale built-environment exposure to 100-year extreme sea levels and sea-level rise, Sustainability 12 (4) (2020), https://doi.org/10.3390/su12041513.
[96] R. Paulik, K. Crowley, N.A. Cradock-Henry, T.M. Wilson, A. McSporran, Flood impacts on dairy farms in the bay of plenty region, New Zealand, Climate 9 (2) (2021), https://doi.org/10.3390/cli9020030.
[97] M. Harrowsmith, M. Nielsen, C. Jaime, E. Coughlan de Perez, M. Uprety, C. Johnson, M. van den Homberg, A. Tijssen, E.M. Page, S. Lux, T. Comment, The Future of Forecasts: Impact-Based Forecasting for Early Action, 2020. https://reliefweb.int/report/world/future-forecasts-impact-based-forecasting-early-action-0.
[98] G. Terti, I. Ruin, S. Anquetin, J.J. Gourley, Dynamic vulnerability factors for impact-based flash flood prediction, Nat. Hazards 79 (2015) 1481–1497, https://doi.org/10.1007/s11069-015-1910-8.
[99] C.A. Williams, G.M. Eosco, Is a consistent message achievable?: defining "message consistency" for weather Enterprise researchers and practitioners, Bull. Am. Meteorol. Soc. 102 (2) (2021) E279–E295, https://doi.org/10.1175/bams-d-18-0250.1.
[100] P. Gorman, Editorial: Why do we need both MetService and Niwa to provide weather forecasts? stuff, https://www.stuff.co.nz/the-press/opinion/85147912/editorial-why-do-we-need-both-metservice-and-niwa-to-provide-weather-forecasts, 2016.
[101] M. Smithson, Conflict aversion: preference for ambiguity vs conflict in sources and evidence, Organ. Behav. Hum. Decis. Process. 79 (3) (1999) 179–198, https://doi.org/10.1006/obhd.1999.2844.
[102] UNDRR, Sendai Framework for Disaster Risk Reduction 2015 - 2030, UNDRR, 2015. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.
[103] J.S. Becker, S.H. Potter, R. Prasanna, M.L. Tan, B.A. Payne, C. Holden, N. Horspool, R. Smith, D.M. Johnston, Scoping the potential for earthquake early warning in Aotearoa New Zealand: a sectoral analysis of perceived benefits and challenges, Int. J. Disaster Risk Reduc. 51 (2020) 101765, https://doi.org/10.1016/j.ijdrr.2020.101765.
[104] C.I. Massey, S.H. Potter, G.S. Leonard, G. Strawbridge, B.J. Rosser, S. de Vilder, Awatarariki Catchment Debris Flow Early Warning System Framework (GNS Science Report 2019/77), 2019.
[105] R. Prasanna, C. Chandrakumar, R. Nandana, C. Holden, A. Punchihewa, J.S. Becker, S. Jeong, N. Liyanage, D. Ravishan, R. Sampath, M.L. Tan, "Saving precious seconds"—a novel approach to implementing a low-cost earthquake early warning system with node-level detection and alert generation, Informatics 9 (1) (2022), https://doi.org/10.3390/informatics9010025.
[106] M.L. Tan, J.S. Becker, K. Stock, R. Prasanna, A. Brown, C. Kenney, A. Cui, E. Lambie, Understanding the social aspects of earthquake early warning: a literature review, Front. Commun. 7 (2022), https://doi.org/10.3389/fcomm.2022.939242.
[107] M.L. Tan, R. Prasanna, J.S. Becker, A.D. Brown, C. Kenney, E. Lambie, D.M. Johnston, K. Stock, D. De Alwis, *Outlook for Earthquake Early Warning for Aotearoa New Zealand: Insights from Initiating a Community-Of-Practice* NZSEE Annual Conference, 2021. https://repo.nzsee.org.nz/handle/nzsee/2350?fbclid=IwAR1_WSDwgIIg5hd03qUXs-DC2kLCxfV5BdnQIy8YU1MP6Z2YiOCQoTYLd4s.
[108] Bush International Consulting, Auckland Flood Response Review, 2023. https://ourauckland.aucklandcouncil.govt.nz/media/je3potln/auckland-flood-response-review_january-27-29-2023.pdf.
[109] C. Massey, K. Leith, Cyclone Gabrielle Landslide Response and Recovery, 2023. https://www.gns.cri.nz/news/cyclone-gabrielle-induced-landslide-mapping-project/. (Accessed 18 December 2023).
[110] Newshub, Weather: Ex-Cyclone Cody could 'directly hit' New Zealand bringing rain, gales, 2022 Retrieved 14 September 2022 from. https://

www.newshub.co.nz/home/new-zealand/2022/01/weather-ex-cyclone-cody-could-directly-hit-new-zealand-bringing-rain-gales.html.

[111] GNS Science, *DART Network Proves Invaluable in Assessing Tsunami Threat Following the Hunga Tonga-Hunga Ha'apai Eruption* GNS Science, 2022 Retrieved 14 September 2022 from. https://www.gns.cri.nz/news/dart-network-proves-invaluable-in-assessing-tsunami-threat-following-the-hunga-tonga-hunga-haapai-eruption/.

[112] A. Gusman, J. Roger, *Hunga Tonga - Hunga Ha'apai Volcano-Induced Sea Level Oscillations and Tsunami Simulations* GNS Science, 2022 Retrieved 14 September 2022 from. https://www.gns.cri.nz/news/hunga-tonga-hunga-haapai-volcano-induced-sea-level-oscillations-and-tsunami-simulations/.

[113] R.V. Lawson, S.H. Potter, S.E. Harrison, M. Clive, Crowdsourced Tsunami and Sound Observations in Aotearoa New Zealand Following the Hunga Tonga-Hunga Ha'apai (HTHH) Tongan Eruption on 15 January 2022, 2022.

[114] Northland Regional Council, Interim Report: Tsunami Activity in Northland Following Hunga Tonga-Hunga Ha'apai Volcanic Eruption, 2022. https://www.nrc.govt.nz/civildefence/how-to-get-ready/tsunami/interim-report-tsunami-activity-in-northland-following-hunga-tonga-hunga-ha-apai-volcanic-eruption.

[115] O. Benfeldt, J.S. Persson, S. Madsen, Data governance as a collective action problem, Inf. Syst. Front 22 (2) (2019) 299–313, https://doi.org/10.1007/s10796-019-09923-z.

[116] M. Janssen, P. Brous, E. Estevez, L.S. Barbosa, T. Janowski, Data governance: organizing data for trustworthy artificial intelligence, Govern. Inf. Q. 37 (3) (2020), https://doi.org/10.1016/j.giq.2020.101493.

[117] D. Rogers, V.V. Tsirkunov, Open Data: A Path to Climate Resilience and Economic Development in South Asia? T. W. B. Group, 2021. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/342901614809536537/open-data-a-path-to-climate-resilience-and-economic-development-in-south-asia 157170.

[118] MBIE, Weather Permitting: Review of open access to weather data in New Zealand, 2017. https://www.mbie.govt.nz/assets/5b3b826f79/weather-permitting-review.pdf.

[119] The World Bank, The Power of Partnership: Public and Private Engagement in Hydromet Services, T. W. Bank, 2020. https://openknowledge.worldbank.org/handle/10986/34615.

[120] NWS. (n.d.). The Weather Enterprise - Working Together to Meet the Needs of Society. Retrieved 6 September 2021 from https://www.weather.gov/about/weather-enterprise.

[121] A. Thorpe, D. Rogers, The future of the global weather Enterprise: opportunities and risks, Bull. Am. Meteorol. Soc. 99 (10) (2018) 2003–2008, https://doi.org/10.1175/bams-d-17-0194.1.

[122] D.H. Sonnenwald, Scientific collaboration, in: B. Cronin (Ed.), Annual Review of Information Science and Technology (ARIST), vol. 41, 2007, pp. 643–681 https://doi.org/10.1002/aris.2007.1440410121, Information Today.

[123] C. Pennington, K. Freeborough, C. Dashwood, T. Dijkstra, K. Lawrie, The national landslide database of great Britain: acquisition, communication and the role of social media, Geomorphology 249 (2015) 44–51, https://doi.org/10.1016/j.geomorph.2015.03.013.

[124] H. Patel, M. Pettitt, J.R. Wilson, Factors of collaborative working: a framework for a collaboration model, Appl. Ergon. 43 (1) (2012) 1–26, https://doi.org/10.1016/j.apergo.2011.04.009.

[125] A.M.B. Lips, R.R. O'Neill, E.A. Eppel, Cross-agency collaboration in New Zealand: an empirical study of information sharing practices, enablers and barriers in managing for shared social outcomes, Int. J. Publ. Adm. 34 (4) (2011) 255–266, https://doi.org/10.1080/01900692.2010.533571.

[126] H. O'Connor, W.J. Hopkins, D. Johnston, For the greater good? Data and disasters in a post-COVID world, J. Roy. Soc. N. Z. 51 (sup1) (2021) S214–S231, https://doi.org/10.1080/03036758.2021.1900297.

[127] C. Schmit, K. Kelly, J. Bernstein, Cross sector data sharing: Necessity, challenge, and hope, J. Law Med. Ethics 47 (2_suppl) (2019) 83–86, https://doi.org/10.1177/1073110519857325.

[128] GeoNet, GeoNet Data Policy – Usage, Acknowledgements, Citations, 2024 Retrieved 19 February 2024 from. https://www.geonet.org.nz/policy.

[129] B.J. Frugis, T. Wasula, Development of Warning Thresholds for One Inch or Greater Hail in the Albany New York County Warning Area, NOAA, 2011. https://repository.library.noaa.gov/view/noaa/6601.

[130] M. Howes, P. Tangney, K. Reis, D. Grant-Smith, M. Heazle, K. Bosomworth, P. Burton, Towards networked governance: improving interagency communication and collaboration for disaster risk management and climate change adaptation in Australia, J. Environ. Plann. Manag. 58 (5) (2014) 757–776, https://doi.org/10.1080/09640568.2014.891974.

[131] H. Blumer, Symbolic Interactionism: Perspective and Method, first ed., University of California Press, 1969.

[132] M.B. Miles, A.M. Huberman, Qualitative Data Analysis: an Expanded Sourcebook, second ed., Sage Publications, Inc, 1994.

[133] M.Q. Patton, Qualitative Research and Evaluation Methods, third ed., Sage Publications, Inc, 2002.

[134] A. Strauss, J. Corbin, Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, second ed., SAGE Publications, Inc, 1998.

[135] B. Chametzky, Generalizability and the theory of offsetting the affective filter, Grounded Theory Rev. 12 (2) (2013).