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ORIGINAL PAPER

Creating equitable learning environments by building on differences in higher education: design and implementation of the MIXED model

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Abstract
Creating truly equitable education is a challenge. Equity, diversity, and inclusion endeavours are often characterized by a depreciative deficit-thinking and a problem-based view on diversity. In this article, we present the MIXED model (Multi-perspective Inclusive eXchanges for Equity and Diversity), which can support lecturers in establishing an inclusive learning environment by building on different perspectives and talents in the (college) classroom. The model offers both inspiration and practical guidance as it describes a vision, strategies, and examples of learning activities for various classroom settings (online/offline, larger/smaller). We also describe the theoretical framework and the process of development and implementation. The MIXED model, developed at the Vrije Universiteit Amsterdam, unpacks three phases in classroom dynamics. Feedback from lecturers indicates utilizing the model can lead to a more equitable learning environment. This approach aims to educate future academics and professionals who are capable of building on the different perspectives in diverse settings when resolving complex societal problems.

Keywords Equitable education · Inclusive learning environment · Inclusive excellence · MIXED model · VU Mixed Classroom Educational Model

Introduction

> In the past 15 years of teaching, I have seen student groups become more and more diverse. This demands a lot from a lecturer. We are expected to be able to just deal with this in our classes, but how to do this is not self-evident at all.
> (Humanities lecturer, focus group, 2018)

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There is a dire need for practical educational tools to establish inclusive learning environments. Despite increased efforts in the last decennium in the field of higher education, educational systems are not yet level playing fields (Taylor et al., 2020; UNESCO, 2020). Apparently, transforming educational practice is tough. Equity, diversity, and inclusion (EDI) interventions often do not bring about the systemic change needed for truly equitable learning environments (Dover et al., 2020). Faculty often lack confidence and efficacy in providing inclusive education (Hall Lang et al., 2023).

Also within the Dutch context, higher education is still characterized by inequality. Students with minority identities drop out more often, study longer, have lower participation levels, and experience lower levels of belonging (Isik et al., 2021; Wekker et al., 2016). Our university, the Vrije Universiteit Amsterdam (VU Amsterdam) which is one of the most culturally diverse universities in the Netherlands, is no exception. A recent study, based on a survey with 1,950 responding students, stresses the need for increased equity and organizational and curricular transformation (Waldring et al., 2020). Students with a minority identity (students who are LGBTQ+, non-binary, international, Muslim, or with a disability or a non-Western migration background) observed exclusion much more often than students from majority backgrounds. They more often felt uncomfortable with the dominant culture, were forced to debunk stereotypes, and were exposed to injurious jokes. Particularly, students with a disability and LGBTQ+ students felt that they were underrepresented in VU's visual material. Nearly half of the students indicated that their curriculum rarely includes different perspectives and examples that reflect various parts of the world.

Unsurprisingly, 'Equity, Diversity, and Inclusion' (EDI) is now a key focus on educational agendas in Europe, including at VU Amsterdam. The need for high-quality education that is inclusive has a sound place in the United Nations Sustainable Development Goals (SDG4: 'Ensure inclusive and equitable quality education') and is specified in the UN Convention on the Rights of Persons with Disabilities (SRPD). Both are ratified by many countries, including the Netherlands. SDG4 summons to 'provide safe, non-violent, inclusive, and effective learning environments for all' (SDG 4a, UN, 2024). Inclusive education thereby goes beyond accessibility. It includes the accommodation 'to the differing requirements and identities of individual students' and focuses 'on the full and effective participation, accessibility, attendance and achievement of all students, especially those who (…) are excluded or at risk of being marginalized' (OCHCR, 2016).

EDI interventions, however, often do not lead to systemic change. They often focus on underserved students and aim to support them in closing gaps in terms of academic skills; also (formerly) at VU. Many EDI interventions intend to familiarize these students with the dominant university norms and codes. In such assimilation approaches, minority students are seen as lacking and are held responsible for closing the gaps (deficit-thinking, see Essed, 2008). These approaches are accompanied by a problem-based view, in which EDI interventions merely focus on solving the 'challenges' that minorities 'bring' to the classroom (Hitch et al., 2015). Creating inclusive education requires teaching that diverts the gaze from 'fixing the minorities' to transforming the system and a revaluation of what diversity can bring to the learning process in higher education (Banks, 1993).

The MIXED model (Multi-perspective Inclusive eXchanges for Equity and Diversity) was designed to shift away from the prevailing problem-oriented approach in our diversity training for educators. Instead, the goal was to create an educational environment where diversity is recognized as an important resource. The MIXED model promotes education that builds on a broad spectrum of diversity in perspectives, approaches, and talents (van der Zee & Otten, 2015). Structured into three phases, this educational model encompasses a vision, which is translated into teaching strategies and more practical learning

activities. The model aims to offer guidance and practical suggestions for lecturers. In this way, it invites lecturers to experiment with the model and design their own education using MIXED principles tailored to their own context.

The MIXED model is not only designed to support educators in creating equitable learning environments (SDG 4 and 4c) but also to help realize future-proof learning outcomes for students. It thereby aims to contribute to SDG4.7, the ambition that all learners learn how to promote sustainable development, including human rights, gender equality, global citizenship, and appreciation of cultural diversity (UN, 2024). The model furthermore aims to strengthen critical thinking, well-balanced, responsible judgements, group collaboration, and communication, which are internationally established learning objectives (Dublin descriptors, Bologna Working Group, 2005).

In the remainder of the article, we first discuss the theoretical framework of the MIXED model. Subsequently, we describe the design and implementation process, followed by an explanation of the model, and lecturer experiences. The article concludes with a reflection on the adoption of the model and the challenges faced so far. For a more elaborate description of the model and examples of practical learning activities, we refer to the VU Mixed Classroom Educational Model handbooks (Ramdas et al., 2019, 2022).

MIXED model theoretical framework

Equitable education engages with multiple perspectives and approaches, including marginalized perspectives (Banks, 1993; Ely & Thomas, 2001; Freire, 1970; Hockings, 2010; Hooks, 2014). This also includes a diverse curriculum that is more inclusive and affirmative for students who are hitherto underserved, lack confidence, and 'feel like a fraud' (Ramsey & Brown, 2018). It repairs epistemic violence; as in the West, Western knowledge has always been considered to be the only truth, erasing and invalidating other 'knowledges' (De Sousa Santos, 2014). In addition, engagement with diverse perspectives, talents, experiences, and approaches enriches education for all. This type of education is also referred to as 'diversity-rich education' (Wekker et al., 2016). Diversity-rich education also aims to equip all students with diversity literacy: a critical and reflexive awareness about diversity, inequality, and positionality that helps them operate in an increasingly complex society in responsible and engaged ways.

In the Dutch context, there is a need for both a diversity-rich curriculum and diversity-rich teaching practices. Students indicate that lecturers often lack the expertise to include different perspectives and to reach out to students with different backgrounds in a meaningful way (Wekker et al., 2016). Commonly, the Western perspective is presented as the only perspective. Furthermore, positionality is often discouraged: participants in the academic learning process are taught not to voice their own opinions, experiences, feelings, and particular interests, as these are deemed irrelevant to the academic programme (Wekker et al., 2016). However, a focus on diversity-rich education can guide future-proof learning outcomes for all students, such as critical thinking, formulating well-balanced, responsible judgements, group collaboration, and communication. These are important '21st-century skills' (Voogt & Pareja Roblin, 2010), which resonate with the international Dublin descriptors (Bologna Working Group, 2005). Learning to truly stay open and knowing how to find solutions and navigate tensions by building on other perspectives and approaches will help prepare students to solve the 'wicked problems' of today (McCune, 2021).

Building on diversity this way requires a focus on the learning environment, which refers to the physical, social, and psychological contexts in which learning occurs

(Fraser, 1998). Inclusive learning environments, where every student feels safe, welcomed, and fully included and where their unique characteristics are acknowledged and valued (see Hockings, 2010; Shore et al., 2011), have a positive impact on academic engagement, self-efficacy, and study success. This applies to all students, but particularly to students with minority identities (Cayubit, 2022; Freeman et al., 2007; Hoffman et al., 2002; Johnson et al., 2007; Thomas, 2012; Tinto, 1975; Zumbrunn et al., 2014). Inclusive learning environments allow for meaningful interactions within the classroom, creating a learning community in which everybody experiences belonging. To facilitate this interaction, students need a safe—or brave—classroom environment to share their individual and minority perspectives, especially when learning from each other's diverse views and experiences (Cook-Sather, 2017). The environment needs to be free from microaggressions and negative stereotypes, whether based on gender, race, or class (Master et al., 2016; Spencer & Castano, 2007; Steele & Aronson, 1995). If students do not experience the classroom environment as safe, they will not only be reluctant to interact, but their learning outcomes will be affected negatively (Cayubit, 2022; Rhodes & Nevill, 2004).

In addition, building on diversity to enrich learning requires deep levels of awareness of lecturers and institutions. This can be quite abstract to translate into practical teaching interventions (Salazar et al., 2010). Creating an inclusive classroom requires recognizing (implicit) assumptions and power structures tied to personal values and educational approaches, and reflecting on positionality, especially of the norm group and mainstream knowledge, including one's own (Banks, 1993; Hooks, 2014). Lecturers are not always confident in the teaching skills that are necessary to do so (Hall Lang et al., 2023) and often feel unequipped to manage the heated discussions that may arise as a result (Müftügil-Yalcin et al., 2023). With the MIXED model, we aim to provide guidance.

To offer this guidance, the MIXED model connects the concepts of diversity-rich education and inclusive environment with group development theory and intercultural sensitivity. Bennett's Developmental Model of Intercultural Sensitivity describes six stages of growing intercultural sensitivity and communication. Starting with denial, where individuals see their own cultural perspective as the only valid view of reality, the model ends with integration, where people deeply understand multiple cultures and can interact effectively across differences (Bennett, 1986). Group development theory describes how groups move through a predictable series of developmental stages that shape a group's functioning and needs as they form and work together towards achieving their goals (Tuckman, 1965). Both group development theory (Tuckman, 1965) and the Developmental Model of Intercultural Sensitivity (Bennett, 1986) describe developmental progression in either group performance (Tuckman) or in increased sensitivity and awareness within intercultural contexts (Bennett). In addition, both theories indicate how dealing with differences (of any kind) can stimulate learning and group cohesion.

Inspired by these concepts and theories, we identified three phases taking place in the classroom in which students, as a group, gradually learn to engage with differences. By progressing through these phases, students may become increasingly aware of the value of diverging perspectives and learn how to build on different perspectives and approaches. To help reach this goal, the model is designed according to the educational principles of constructive alignment, backwards design (Biggs & Tang, 2015), and active learning (Ballen et al., 2017; Schneider & Preckel, 2017).

Designing and implementing the educational model

The VU MIXED model was developed at the Vrije Universiteit Amsterdam (VU), one of the most diverse research universities in the Netherlands in terms of students' cultural background. The model was developed in two stages through a collaboration between the VU International Office, the VU Diversity Office (MS, KvdZ), the VU Centre of Teaching and Learning (CTL) (SR), and experts from various faculties.

In 2017, a training programme called 'Mixed Classroom in Practice' was initiated by VU International Office. The training programme specifically focussed on lecturers' skills in adapting to an increasingly dynamic and diverse educational landscape. It was developed using input from focus groups (32 lecturers from six faculties), about lecturers' needs for establishing inclusive and equitable learning environments. These focus group meetings were recorded, and detailed notes were taken to capture reactions and ideas shared by participants. Inductive thematic analysis was then used to identify the challenges and opportunities within 'international classrooms' and otherwise 'diverse classrooms' as discussed by lecturers. The key challenges identified included establishing an inclusive learning environment and developing a shared understanding of what an inclusive learning environment means. Additionally, navigating divergent perspectives within a classroom context emerged as a challenge, whether political or otherwise. Notably, while educators recognized the potential for learning opportunities arising from the diversity within student groups, they reported a lack of effective strategies to fully leverage this potential. They often felt insecure or hesitant to act. They furthermore articulated the need for structural support. These challenges formed the starting point for the development of our educational model.

Mirroring the traditional tension between 'global education' and 'multicultural education', which primarily focuses on the domestic context (Charles et al., 2013), also at our university, the 'international classroom' and the 'diverse classroom' were hitherto approached separately. The term 'Mixed Classroom' was coined, bridging the gap between the two perspectives. Although chosen because of its neutrality in the Dutch context, we realize that this term can cause confusion in an international context, as it is sometimes associated with controversial attempts to deliberately 'mix' people. To weaken this connotation but remain recognizable in the Dutch context, we renamed it the MIXED model: Multi-perspective Inclusive eXchanges for Equity and Diversity.

In the second phase, in 2019, we (the authors) developed the training into an encompassing educational model. Feedback was sought from individual professors and educational experts across the university through two focus groups (25 lecturers and students), and a steering group consisting of educational leaders representing various faculties, policy advisors, and a student member. In February 2020, the VU Mixed Classroom Educational Model—now MIXED model—was officially presented. Nowadays, it is an integral component of the VU's educational strategy. The MIXED programme, coordinated by the Centre for Teaching and Learning, offers materials (website, handbooks), training, and tailored advice, and is offered to lecturers and educational leadership inside and outside VU.

Within VU, the model has been rolled out via three approaches. (1) A voluntary MIXED training programme is offered to all teaching staff (150 participants so far). Alumni are invited to co-teach in subsequent trainings and form a MIXED education community. (2) Secondly, the MIXED model has been integrated into the regular professionalization programmes. It is now an integral part of the university-wide University

Teaching Qualification (UTQ) programmes, which reach approximately 200 lecturers annually. In addition, an inclusive leadership programme has been designed that builds on the MIXED model. (3) The VU Centre for Teaching and Learning offers customized support to lecturers or departments.

The MIXED model (Multi-perspective Inclusive eXchanges for Equity and Diversity)

The MIXED model describes three phases taking place in the classroom in which students gradually learn to engage with differences. By progressing through these phases, students may become increasingly aware of the value of diverging perspectives and learn how to build on different perspectives and approaches. Each phase is connected with specific guiding questions (evidence-based) strategies and learning activities, all grounded in academic literature.

The three phases are (see Fig. 1):

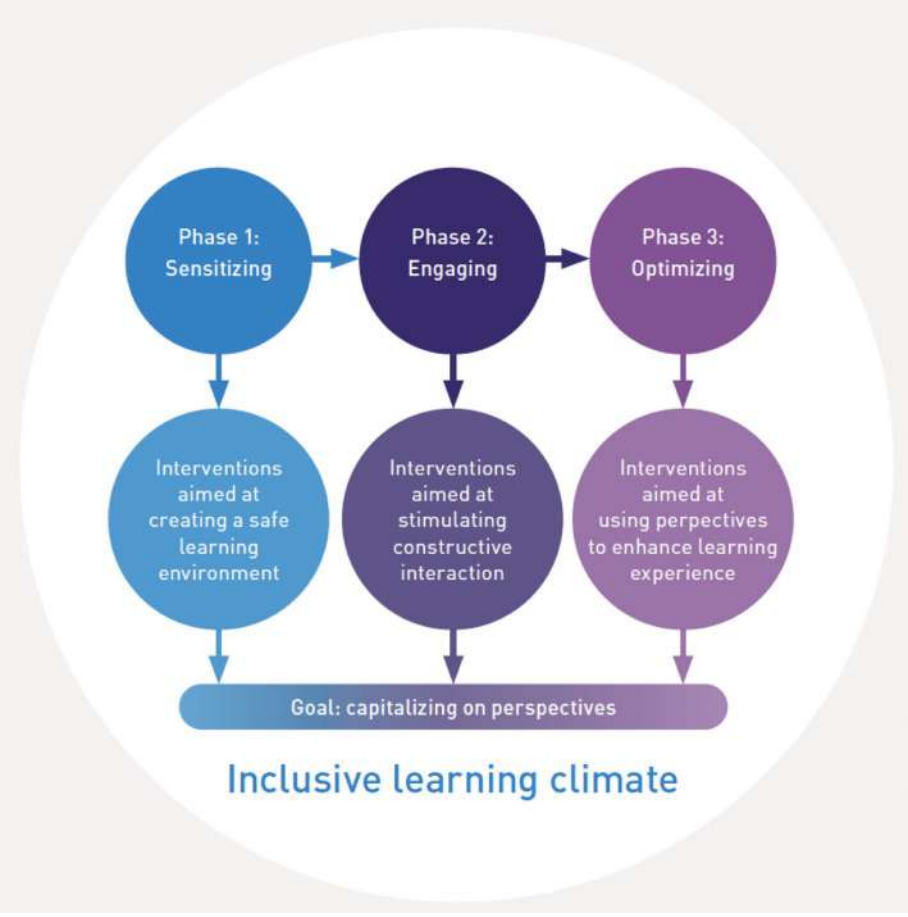

Fig. 1 The 3-phased MIXED model (formerly VU Mixed Classroom Educational Model, Ramdas et al., 2019)

1. **Sensitizing** students to their own frame of reference and the existing diversity in the classroom, and creating a safe learning environment to do so;
2. **Engaging** students to interact constructively with different perspectives present in the classroom;
3. **Optimizing** every student's learning process by having them build on different perspectives and approaches.

In practice, this is not a linear process. Phases can overlap and be cyclical. The time needed to complete all three phases depends, for example, on course content, level, learning goals, and group dynamics. Below, we will discuss each phase, illustrating it with guiding questions for lecturers and teaching strategies. We refer to the VU Mixed Classroom Educational Model handbooks for learning goals per phase and more elaborate examples of practical learning activities (Ramdas et al., 2019, 2022).

Phase 1 sensitizing: goal, strategies, and learning activities

The first phase focuses on two main goals: *sensitizing students to their own frame of reference and the existing diversity in the group, and creating an inclusive learning environment*. Students explore their own frame of reference with respect to other perspectives. It takes time and practice to recognize that views and approaches that are taken as the (self-evident) norm are not the only ways to approach a subject or learning-activity, and to recognize that other perspectives can have value and legitimacy as well (Bennett, 2004; van der Zee & van Oudenhoven, 2017).

Questions guiding the lecturer in this phase are: How do I create an inclusive learning environment that invites students to share their perspectives? How can I stimulate students to examine their own frame of reference? How do we frame diversity in a positive way? What are my own assumptions regarding 'good teaching' and 'good students'?

The following strategies and activities support learning in this phase.

- *Reducing anonymity*—through introductory exercises and interaction in smaller groups—makes students feel seen and heard, which encourages them to interact and share their perspectives (Ambrose et al., 2010; Carroll, 2015).
- *Exploring values and assumptions*, in the first place one's own frame of reference, creates openness to other perspectives (Bennett, 2004).
- *Establishing guidelines for interaction*, through co-creation—like a plenary brainstorm, dialogue, or an anonymous poll—helps to establish an inclusive environment (Ambrose et al., 2010; Carroll, 2015).
- *Monitoring the learning environment* is needed to track student experiences (Ambrose et al., 2010). This is preferably done anonymously, for example, by students leaving comments on an online tool or an 'exit slip'.
- *Inducing shared identities* is a bottom-up way to embrace the varying individual identities (Jans et al., 2012). For example, through an introductory exercise that invites students to indicate what unique and valuable skills they bring to a collaboration.

Phase 2 engaging: goal, strategies, and learning activities

In phase 2, students learn *how to interact with perspectives, approaches, and styles different from their own*. When students feel safe enough to share their own points of view, they can start engaging and interacting with other perspectives in open-minded and constructive ways.

Guiding questions for lecturers in this phase are: How do I get my students to collaborate constructively? How do I teach my students to be open to other perspectives? How do I keep the learning environment safe and inclusive while interaction takes place? How do I deal with tension?

Bringing differences to the surface can lead to tension. These so-called 'hot moments' can be great opportunities for learning. However, they can also jeopardize the inclusive learning environment and negatively interfere with the learning process (Warren in Carroll, 2015). Hence, this phase can be challenging for both students and lecturers. Lecturers need to develop sensitivity to rising tensions and learn to respond to unexpected events in reflective ways (Müftügil-Yalcin et al., 2023). Interventions in this phase are geared towards students practising interacting with different approaches and perspectives in constructive ways.

The following strategies support learning in this phase:

- *Structured interaction with other perspectives* makes students constructively and purposefully interact with diverging perspectives. For example, through writing a speech, playing the devil's advocate, or presenting a grid with pros and cons.
- *Creating 'in between' spaces for interaction*, where everyone steps back from their taken-for-granted positions with curiosity, opening up space for other perspectives or approaches and encouraging meaningful interactions (Ghorashi, 2006).
- *Dispelling the illusion of explanatory depth* helps students recognize the limitations of their assumptions and knowledge (Rozenblit & Keil, 2002); for example, by asking students to research a standpoint that is opposite to their own.
- *Integrative conflict management* helps turn friction and 'hot moments' into learning opportunities (Carroll, 2015; Müftügil-Yalcin, 2023; Rognes & Schei, 2010). By taking a step back, participants jointly explore the various sides and interests of a situation by asking questions such as: What is the source of our disagreement? Which assumptions are involved? What additional information can resolve this?
- Reinforcing interaction guidelines and monitoring the learning environment helps preserve the inclusive learning environment.

Phase 3 optimizing: goal, strategies, and learning activities

Phase 3 aims to *optimize every student's learning process by building on different perspectives*. The focus is on the combination and integration of different perspectives to stimulate critical thinking, cognitive flexibility, and creative problem-solving. Differences among students are acknowledged and used to enhance problem-solving creativity, provided that the class interactions are guided well (Nakui et al., 2011).

Guiding lecturer questions in this phase are*:* How do I make sure all students learn from different perspectives? How do I guide group collaborations in such a way that students

truly capitalize on their differences? How can I help my students make explicit what they learn from each other?

The following strategies support learning in this phase:

- *Structured combining of perspectives* makes students not only interact with other perspectives but combine them and integrate them into new insights; for example, through a 'jigsaw' exercise, in which students possess different fragments of information of a larger problem (Doymus, 2008).
- *Switching between perspectives* makes students develop cognitive flexibility and learn to consider things from fresh and different perspectives—something minority students are often already quite skilled in (Benet-Martínez et al., 2006).
- *Active reflection on their learning process*, including reflection on MIXED skills, strengthens student-learning (Laird et al., 2014). Exercises that train reflective skills—such as a 'one-minute-paper' in which students formulate insights from a group exercise (Paulson & Faust, 2019)—teach students how to navigate situations without clear-cut answers.
- *Regular formative assessment*, consisting of constructive feedback from peers and lecturers, supports learning. To conform to the principle of constructive alignment (Biggs & Tang, 2015), it is important to check whether students have reached MIXED learning goals and explicitly integrate MIXED goals into the programme's intended outcomes.

Table 1 provides an overview of the learning goals, strategies, and activities of the three phases. For details, see Ramdas et al (2019).

Lecturer experiences

In 2022, twenty lecturers who followed the MIXED training programme or used the model in their teaching shared their experiences in semi-structured interviews (De Rooij, 2022). They employed the model in varying ways: some completely restructured their course to fully implement the model, while others used parts of the model to facilitate more active, dialogue-based learning. Lecturers describe:

> 'I really appreciate this line of thought and model because I am confident it will support students to develop critical thinking skills that are needed in an academic world.' (Lecturer's reflection)
> 'Engaging in reflective conversations on identity and intersectionality, and increasing my awareness of hot moments, implicit bias, and mitigation strategies have unquestionably deepened my understanding of the oppressions, challenges, and opportunities in this field' (Lecturer's evaluation form)

Lecturers mentioned various benefits of the model. It helped them to teach students to collaborate, to approach issues from different perspectives, and to become more inclusive and more respectful towards each other's differences. They also described how the model supported them when addressing sensitive topics and creating the safe space needed. Most lecturers experienced MIXED model teaching as a more activating way of teaching, with students actively engaging with the content. In addition, they appreciated the broadly applicable range of examples of practical learning activities (De Rooij, 2022).

The biggest dilemmas lecturers encountered when implementing the model concerned the time investment. Some lecturers struggled to balance their educational responsibilities

Table 1 MIXED model learning goals, strategies, and learning activities (Ramdas et al., 2019)

Phase	Learning goals	Strategies	Learning activities
1. Sensitizing	Students are able to reflect on their own frame of reference, and demonstrate awareness of their own perspective being not necessarily a universal perspective; Students are aware of, and can articulate the importance of 'openness' towards other perspectives and approaches Students know what a safe learning environment entails and how they can contribute to it	Reduce anonymity Explore values and assumptions Establish ground rules for interaction Monitoring learning environment Induction of identities	What shaped you? Card system Circle of trust Exit slips Personality tree/rose Tiles Fifty seconds Buddy system Getting to know you Contract Dotmocracy From judgement-to-question Three-step-interview
2. Engaging	Students recognize and are willing to explore perspectives and approaches that differ from their own Students are able to constructively interact with these perspectives Students recognize unease and tension when they arise in interactions, and have practised dealing with them	Structuring interaction with other perspectives Creating 'in between' spaces for interaction Dispelling the illusion of explanatory depth Integrative conflict management Reinforcing ground rules/monitoring learning environment	Speech writing/letter writing Affective response Devil's advocate Buzz duo's Predict, Observe, Explain Pro/Con grids Speed date Questions only/Quescussion Idea line up Debate Rotating Chair

Table 1 (continued)

Phase	Learning goals	Strategies	Learning activities
3. Optimizing	Students actively seek and consider perspectives and approaches different to their own; Students are able to switch between these perspectives and approaches; Students are able to integrate and combine perspectives when analysing problems or cases Students can demonstrate combining different perspectives to formulate creative solutions, both on individual and group level	Combining perspectives in a structured way Switching between perspectives to stimulate cognitive flexibility Reflecting on learning process Rewarding students for capitalizing on perspectives	One-minute-paper Big paper Think aloud Jig Saw/Expert exercise Student-led sessions Chain notes Solving the problem Index card pass Tag team discussion World Café exercise

with research tasks. Pressured to prioritize research, it left them too little time to integrate the MIXED model into their teaching. Second, they found that a focus on course content did not leave much time in their lectures or tutorials to dedicate to the student-centred, active learning activities as suggested by the model. Third, large student groups, reduced time for tutorials, and the high perceived workload made it difficult for lecturers to implement new ways of teaching and apply the model. Furthermore, some lecturers mentioned that the effects of using the model were not always clear or that they did not see the relevance of including diverging perspectives in some courses, for example, in statistics (De Rooij, 2022).

The following descriptions illustrate courses designed based on the MIXED Model:

> In a VU Master's course (Beta – 145 students), the instructor makes students work in groups on 'wicked problems' such as overfishing or nitrogen deposition. Students take the perspectives of varying stakeholders. To ensure that students work constructively and remain truly open to each other's views, the course begins with a reflection on the different backgrounds and perspectives of the students themselves. Subsequently, students explore opposing viewpoints in pairs. In the final assignment, they have to build on each other's perspectives to develop solutions for their wicked problems.
>
> In a Master's course on Ethics, the MIXED approach is implemented in an 'active blended' way. Sensitizing (phase 1) takes place before the lectures in the form of an online interactive assignment in which students get to know each other and answer each other's questions. Phase 2 (engaging) is used during the lectures; students work in small groups on cases, adopting a specific philosophical perspective. After the lectures, students apply phase 3 (optimizing) in reflection assignments, in which they have to approach an ethical problem from different perspectives.

Challenges and limitations

Implementing the educational model is not always easy. First of all, we found that for many educators and students, MIXED education requires a change of view on the role of education and of the lecturer. Often, particularly in higher education, the main educational focus is on cognitive aims and the lecturer is seen as a 'neutral', distant, all-knowing expert: the 'banking model of education' (Freire, 1970). It is then a large transformation to implement MIXED education, with its participatory approach, emphasis on personal development, engagement with diversity, and reflection on the positionality of the curriculum and of people (including the lecturer). For most lecturers and students, this personal and vulnerable approach feels uncomfortable at first. We also see that many educators find it hard to reflect on the mainstream canon in their field, to put into perspective the knowledge that they have come to see as the unquestionable foundation of their discipline.

Moreover, even though in our institution inclusive MIXED education is now one of the strategic spearheads, lecturers experience disapproval and mention that their efforts in creating inclusive education are sometimes seen as frivolous or 'soft' (De Rooij, 2022), resulting in them using the model under the radar. In addition, as mentioned before, if there is not an obvious link between student perspectives and course content, lecturers find it more challenging to apply the principles outlined in the model (De Rooij, 2022). Furthermore, most MIXED initiatives are not obligatory for lecturers, making it hard to reach those who do not see value in using the model. Finally, while feedback from lecturers utilizing the

model suggests its potential to foster more equitable learning environments, more research is still required to evaluate the impact of the educational model.

Concluding remarks

Central to the MIXED model is diversity-rich education, intercultural sensitivity theory, and group dynamics theory, combined to help students gradually learn to build on diverse perspectives and create equitable learning environments that are accessible, affirmative, and relevant to every student (Rogahang, 2024). It can also support the development of critical, reflexive, inclusive, and sustainable behaviour (Voogt & Pareja Roblin, 2010). Although some might assume the MIXED model only serves education dealing with supposedly sensitive topics, we like to stress that inclusive education is important in every context and discipline, including Medicine and STEM (Grunspan et al., 2016; Ulriksen et al., 2010). Learning processes take place in social settings. They are guided by implicit and explicit rules, norms, and assessments and impacted by hierarchies in knowledge perspectives, methodological approaches, or learning strategies (Banks, 1993; Caroll, 2015).

The design of the model allows educators with varying degrees of autonomy to implement the model on various levels (class, course, programme, institution) in various degrees of intensity, from experimenting with single learning activities to an encompassing implementation in a programme. Feedback from lecturers tells us they adapt strategies and activities to their own preferences and context (discipline, group size). The options provided by the model could address a common challenge faced by EDI initiatives: the perception that such policies infringe on individual lecturers' autonomy (Pizarro Milian, 2023). However, even though the MIXED model primarily addresses lecturers, it is important to realize that lecturers are only a part of the larger educational machinery. Although lecturers and teachers play a big role in creating inclusive environments (Hattie, 2012), they alone cannot change the educational system. Nor does the responsibility to do so solely lie with them: the institution's responsibility for creating inclusive education cannot be overstated (Pizarro Milian, 2023). The larger machinery of the institution shapes assessment criteria for both lecturers and students; shapes the norms about what is 'a good student', 'a good lecturer', and a 'good education'; offers (or lacks) facilities and flexibility in time and space; and supports (or lets down) innovative lecturers. Hopefully, this responsibility to create more inclusive and enriching education, for example, through adopting MIXED education, will be taken up as a joint endeavour by all parties.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose, nor any conflicts of interest to declare that are relevant to the content of this article.

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Emotional intelligence, support, and organizational culture's impact on decision-making: mediation and moderation analysis in academia

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Abstract

Academic decision-making is composite, involving a number of players with various points of view and frequently conflicting interests. This study explored the relationship between emotional intelligence competence, organizational support, complexity of the academic environment, and role seniority on decision-making efficiency in academia, with a focus on the moderating-mediating role of organizational culture and job satisfaction. Conducted in Pakistan, the study targeted a diverse sample of 1227 individuals from various academic institutions, including deans, department heads, administrative staff, faculty members, research scholars, and postgraduate students, selected using a stratified random sampling method. This study proposes a comprehensive model for higher education decision-making dynamics using behavioural and institutional components, particularly in developing countries like Pakistan. The findings suggested that emotional intelligence competence, organizational support, complexity of the academic environment, and role seniority all have significant direct effects on academia decision-making efficiency (ADME). Furthermore, job satisfaction of university staff was found to mediate the relationship between these variables and ADME, while organizational culture of the university moderated the effects of the independent variables on ADME. The findings provide a framework for development of an effective decision-making culture in academia, highlighting the need for institutions to prioritize the well-being and satisfaction of their staff in order to optimize decision-making processes.

Keywords Emotional intelligence, Organizational support, Organizational culture, Job satisfaction, Academia, Pakistan

1 Introduction

Unlocking the potential of decision-making efficiency in academia is a multidimensional endeavour that links emotional intelligence, support mechanisms, and organizational culture. In academia, the strategic decisions have an effect on research directions,

policies, and institutional development [53, 78]. Therefore, understanding the factors that influence decision-making processes is vital for effectiveimplementation.Academic decision-making is composite, involving a number of players with various points of view and frequently conflicting interests. This emphasizes the significance of taking into account not just the intellectual aspects of decision-making but also the socio-emotional elements that influence human behaviour [43]. Emotional intelligence is increasingly recognised as a key determinant of effective leadership and decision-making [52, 68, 83]. Furthermore, the presence of robust support mechanisms within academic institutions can significantly influence decision-making processes by nurturing a supportive and conducive atmosphere [81, 96].Moreover, the all-encompassing organisational culture within academic institutions sets the tone for decision-making processes [31]. By examining the moderating and mediating effects of organisational culture and job satisfaction, this study seeks to explore the mechanisms through which emotional intelligence and support mechanisms influence decision-making processes in academia. By doing so, it aims to deliver valuable insights that can make decision-making better along with promoting a positive work environment within academic institutions.

Efficient decision-making is integral to the success of academic institutions worldwide, facilitating the advancement of knowledge, student success, institutional reputation, and optimal resource allocation. In the context of Pakistan, where demands for quality education are high and multiple challenges in higher education exists [46, 70], efficient decision-making gains added importance. Furthermore, an appreciation of the cultural and societal milieu is imperative for navigating decision-making processes effectively [102], thereby ensuring the alignment of academic institutions with their mission of advancing knowledge, serving society, and fostering educational progress in Pakistan. Emotional intelligence (EI), encompassing the ability to perceive, understand, manage, and influence emotions, holds significant relevance to decision-making processes in academia. Acknowledging the pivotal role of EI and nurturing these competencies among academic leaders and stakeholders, institutions can enhance their capacity for collaborative decision-making, innovation, and positive organisational culture, ultimately contributing to their success and effectiveness [1, 56]. EIC enables academic leaders and stakeholders to navigate the intricate tapestry of interpersonal dynamics [105], facilitating stress mitigation and fortifying resilience [49, 59]. Additionally, EIC contributes to ethical decision-making by promoting empathy, integrity, and consideration of diverse perspectives, thus ensuring that decisions align with ethical principles and serve the best interests of stakeholders [9, 26, 51]. In Pakistan, emotional intelligence (EI) profoundly influences decision-making efficiency among academic professionals [14]. EI enables individuals to navigate complex social dynamics, foster positive relationships, and facilitate open communication, streamlining decision-making processes and reducing conflicts.

Recently, organisational support (OS) has emerged as a cornerstone in shaping academic decision-making processes [35]. By providing resources, information, and guidance, OS equips decision-makers with the tools needed to make informed and effective decisions. Moreover, OS fosters a supportive work environment characterised by collaboration, trust, and respect, which enhances decision-making efficiency by encouraging open communication, teamwork, and shared decision-making processes [88]. Additionally, OS plays a crucial role in promoting ethical conduct by reinforcing integrity, transparency, and accountability within academic institutions [69]. Through initiatives aimed

at mitigating stress and burnout, OS ensures that decision-makers can maintain well-being and sustain high performance [50]. Academic institutions in Pakistan furnish an array of support mechanisms aimed at facilitating decision-making processes and augmenting the efficacy of academic professionals [33]. Primarily, mentorship programmes intertwine senior faculty members with their junior counterparts, furnishing guidance and bolstering support to navigate the labyrinth of academic responsibilities and grasp career development opportunities. Additionally, academic institutions offer training and professional development workshops to enrich decision-makers' proficiency across domains such as leadership, communication, and strategic planning. However little counselling and wellness services are available to support academic professionals' mental health and well-being.Nonetheless, these pillars of support assume paramount significance in empowering academic professionals to make informed, ethical, and effective decisions that contribute to the advancement of academic institutions in Pakistan [65]. The complexity of the academic environment (CAE) presents significant challenges that can impact decision-making efficiency among academic professionals, particularly concerning seniority levels. Decision-making procedures are made more difficult by the complex, multifarious structure of academic institutions, which include a wide range of stakeholders, conflicting objectives, and changing trends. The consequences of CAE on the effectiveness of decision-making highlight the value of flexible leadership, cross-disciplinary teamwork, and strategic vision in tackling the opportunities and problems inherent in academic settings. Decision-making procedures are made more difficult by the complex, complex structure of academic institutions, which include a wide range of stakeholders, conflicting objectives, and changing trends. The consequences of CAE on the effectiveness of decision-making highlight the value of dynamic leadership, cross-disciplinary teamwork, and strategic vision in tackling the opportunities and problems inherent in academic settings.

Layers of complexity characterize Pakistan's academic landscape, which is diverse and continuously changing. First of all, there is additional complexity due to the hierarchical structure of academic institutions in Pakistan, which has numerous levels of governance and administration. Decisions may need to be approved by a variety of authorities. Additionally, given Pakistan's socio-political backdrop, cultural norms, political dynamics, and economic difficulties, in addition to resource shortages and inadequate facilities in many academic institutions, pose formidable obstacles to decision-makers, tasked with the delicate balancing act of competing priorities and judicious resource allocation(Sain & Babiera II, 2023). Notwithstanding these difficulties, Pakistan's complicated academic landscape offers chances for creativity, cooperation, and constructive transformation. Academic professionals may effectively negotiate complexity while making informed decisions that promote their institutions' aims and contribute to the development of Pakistan's academic sector by utilizing their knowledge and organizational support mechanisms. Since role seniority (RS) includes knowledge, autonomy, leadership, and mentoring responsibilities among senior academic professionals, it plays an important part in academic decisions. Senior academics have years of experience and knowledge build-up, which gives them a thorough awareness of discipline patterns and institutional dynamics. This insight enables them to take strategic decisions that are in line with institutional objectives [101]. In addition, their leadership roles provide them with independence and power to act quickly in the face of difficulties, distribute resources wisely, and

carry out imaginative endeavours. But it's important to understand that seniority by itself does not ensure good decision-making because obstacles and biases might make decision-making less effective [57, 109]. Academic institutions may promote a culture of diversity, inclusion, and ongoing learning by maximise the potential of seniority in promoting effective and ethical decision-making within academia, ultimately advancing institutional goals and contributing to societal progress.

The research questions of this study are firstly how do emotional intelligence competence (EIC) and organizational support (OS) contribute to enhancing Academia Decision-Making Efficiency (ADME) in the context of complex academic environments (CAE) and role seniority (RS).This inquiry is significant as it aligns with the multifaceted nature of decision-making in academia, where understanding socio-emotional factors alongside rational aspects is crucial [43, 81, 90]. By exploring this relationship, we aim to uncover the nuanced dynamics that influence decision-making effectiveness in academia, providing insights for fostering a supportive and conducive decision-making environment. Secondly, to what extent does Job Satisfaction of University Staff (JSUS) mediate the relationship between EIC, OS, CAE, and RS on ADME.This investigation is essential as it sheds light on the mechanisms through which emotional intelligence, organizational support, and other factors impact decision-making efficiency via job satisfaction [1, 4, 88]. Understanding this pathway is critical for enhancing decision-making processes by addressing employee satisfaction, ultimately contributing to a positive work environment and organisational success. Lastly, how does the Organizational Culture of the University (OCU) moderate the relationship between EIC, OS, CAE, and RS on ADME and JSUS.This exploration is significant as it elucidates how the broader cultural context within universities influences the effectiveness of individual and organizational factors on decision-making efficiency and employee satisfaction [31, 102]. By recognising the moderating role of organizational culture, we intend to offer insights for aligning cultural norms and practices with decision-making, and at the same time promoting a conducive environment for effective decision-making and academia well-being. To answer the above questions, the research objectives are formulated as following:

- To examine the combined influence of emotional intelligence competence (EIC), organizational support (OS), complex academic environments (CAE), and role seniority (RS) on academia decision-making efficiency (ADME).
- To investigate the mediating role of job satisfaction of university staff (JSUS) in the relationship between EIC, OS, CAE, and RS on ADME.
- To explore the moderating effect of organizational culture of the university (OCU) on the relationship between EIC, OS, CAE, and RS on ADME and JSUS.

The study provides vital new insights into academic institution decision-making and organizational behavior. First, the study developed an integrated model that accounts for emotional intelligence, managerial support, academic environment complexity, and work seniority's direct academic decision-making effectiveness influencing effects. These determinants have typically been studied independently or in small organizational contexts. Still, this study is one of the few to analyze their combined impact on higher education, presenting a full picture. Second, the study deviates from linear models to examine more complex interaction effects that better reflect decision-making in different institutional contexts by using organizational culture as a moderating factor and

university staff job satisfaction as a mediating variable. Third, a large, stratified random sample of academics—deans, department heads, professors, administrative staff, and postgraduate scholars—improves practicality and generalizability. This research provides fresh insights that might inform leadership and institutional initiatives in Pakistan, a developing country with various cultural and structural constraints. The objective is to make decision-making settings more responsive, inclusive, and emotionally intelligent. The results have major implications for educational systems in comparable socio-cultural contexts, academic administration, and human resource development.

Leadership style, administrative frameworks, and structural decision-making models have been extensively studied in higher education organizational behaviour and governance [55, 103]. However, psychological and cultural factors affecting academic decision-making have received less empirical attention. Institutional complexity [76], organizational support [29], and emotional intelligence [71] have been studied separately. However, there has been little effort to combine them into a single model that accounts for role hierarchy and institutional culture. There is little study on how job happiness and organizational culture influence academic decision-making, especially in developing countries like Pakistan. This research addresses a crucial need by examining how emotional intelligence, organizational support, academic difficulty, position seniority, work happiness as a mediator, and organizational culture as a moderator affect university decision-making. The research problem lies in the lack of behaviour-based models that explain how individual and institutional factors impact academic decision-making outcomes. The study fills this knowledge vacuum by providing theoretical foundations and practical advice for enhancing tertiary governance and performance.

2 Literature review

Emotional intelligence (EI), support mechanisms, organisational culture, and job satisfaction influence strategic decision-making in academia. This study contributes to understanding EI's significance in managerial decision-making and highlight the contextual complexities within academic environments, offering practical insights for cultivating effective decision-making cultures in various industries. There are 3 main subsections for analysis of the literature.

2.1 Emotional intelligence competence (EIC), organizational support (OS) and decision-making efficiency in academia

In academia, emotional intelligence and organisational support are crucial for decision-making efficiency. Emotional intelligence allows a person to understand emotions of himself and others, helping in making effective, meaningful communication and resolution of conflicts. An organisational environment which fosters collaboration and encourages innovation, creating an atmosphere of trust and psychological safety. When decision-makers feel valued and supported, they are more empowered to make informed decisions efficiently, driving academic success [62]. Examined how the work performance of Indonesian guidance and counselling instructors at all junior high schools in the Deli Serdang, North Sumatra, area was affected by altruism, emotional intelligence, and decision-making. 259 instructors from both public and private junior high schools in the area made up the population, while 175 students made up the study's sample. Decision-making and work performance were influenced by emotional intelligence with

0.135 and 0.352, respectively. As a result, the study emphasized how crucial it is that regional school principals give teachers plenty of space to develop their compassion, emotional intelligence, and decision-making skills [59]. Studied the importance and value of emotional intelligence (EI) in the development of teachers professionally and its impact on quality of teaching. The relationship between EI and factors including Stress Coping Strategies, Social Self-efficacy, and Decision-Making Styles among higher education teachers were explored. The study proposed a conceptual model aimed at enhancing teaching quality by improving workplace social interactions, decision-making, and reducing teacher attrition rates. The article reviewed prior research to support the development of this conceptual framework, highlighting how domain knowledge in this area can lead to better stress coping, decision-making, and morale among teachers, thereby reducing attrition rates. The study advocated for the consideration of EI as an assessable component in teacher recruitment processes.

[54] did a study that focused on the importance of emotional intelligence (EI) in higher education, that focused on teachers' abilities to recognise and regulatetheir emotions to improve teaching results. The research sample consisted of 312 teachers from 25 higher education institutes in the United Arab Emirates (UAE). Emotional Intelligence Competencies were assessed using Costa and Faria's EQ test, alongside the Reuven Bar-On emotional intelligence scale for data collection. Structural equation modelling (SEM) was employed to evaluate a proposed model for EI-based teaching competencies and their relationship to critical strengths. Results demonstrated that Emotional Intelligence Competencies significantly influenced educator behaviour, subsequently enhancing student success. The study recommended higher education institutes to recruit instructors with high EI skills and provide training sessions to enhance existing educators' EI abilities for successful instruction and improved performance [16]. Investigated the role of emotional intelligence (EI) in leadership within higher education, a field where empirical support for EI application remains scarce. Using semi-structured interviews and a qualitative descriptive design, faculty perceptions of leader EI behaviour and its impact on engagement were analysed. Results highlighted the significance of emotional intelligence as a vital skill for academic leadership. Specifically, relationship management, empathy, self-management, and self-awareness were identified as critical EI abilities that contribute to greater staff engagement. The study advocated for university administrators and policymakers to consider emotional intelligence as a criterion for leadership selection and placement in higher education [67]. In a study conducted in Turkey, examined the impact of emotional intelligence training on adolescent problem-solving and decision-making skills using a real experimental model. Twenty-two secondary school students participated, with pretest - post test controls. Emotional intelligence training significantly improved decision-making skills, evidenced by higher emotional intelligence levels and better problem-solving abilities in the experimental group compared to controls. However, limitations such as sample size and generalizability were noted.

[20] in his study explored how employee motivation and leaders' decision-making is being influenced by Emotional Intelligence (EI).The population of the study consisted of respondents from private higher education institutions in Afghanistan's Nangarhar Province. Data from 176 respondents were collected through stratified random sampling. Results suggested that EI is crucial for employee motivation and effective leadership decision-making in private higher education settings. Correlation and regression

analyses, revealed significant positive associations (56% for motivation, 67% for decision-making) between EI and both variables. Regression models indicated EI explained 51.8% of employee motivation and 55.1% of leader decision-making variance [110]. Emphasized the importance of emotional intelligence (EI) for MBA program directors, faculty and students. They highlighted how EI enhances leadership communication, decision-making, and education in MBA programs, and stressed the importance of encouraging learning, growth, and professional development. Leaders with high EQ are adept at managing emotions, promoting self-awareness, empathy, and the social skills necessary for student-teacher interaction. They create a welcoming environment that encourages dialogue, trust and cooperation, and resolve conflicts diplomatically to preserve relationships and cooperation Strong EI improves leadership judgments, considering numbers, emotions, and relationships for informed decisions that foster academic and personal growth. The authors advocated for selecting MBA program directors based on EI to elevate academic settings and student outcomes through empathetic leadership [85]. Investigated the relationship between emotional intelligence and organisational citizenship behaviour (OCB) among college teachers in the arts and science stream. They distinguished between defined role behaviour, pertaining to official duties, and extra role behaviour, encompassing voluntary actions beyond official tasks. Their research, involving 288 teachers from different colleges in Kancheepuram district, employed self-assessment measures for emotional intelligence and OCB. Statistical analyses including correlation, one-way ANOVA, and multiple linear regression revealed a moderate positive relationship between emotional intelligence dimensions and OCB. Emotional intelligence was found to account for 41% of the variance in OCB among college teachers [15]. examined the relationship between emotional intelligence, grit, and decision-making in emerging adults aged 18 to 24 years and how to Manage their own and others' emotions, tested alongside decision-making ability. Using a sample of 176 participants, the study used the Grit Scale, Emotional Intelligence Self-Assessment Tool, and Decision-Making Questionnaire, analysed using SPSS The results revealed a significant positive relationship between emotional intelligence and decision making ($p < 0.01$), as well as emotional intelligence and grit ($p < 0.05$). However, no significant relationship was found between grit and decision-making.

[82] investigated the influence of perceived organizational support, organizational values system, and job satisfaction on organizational commitment. They proposed a model linking internal organizational procedures, employees' perceptions, job satisfaction, and loyalty. Data from 210 faculty members and teachers from various Pakistani universities were collected online using convenient sampling and a cross-sectional method. Regression analysis supported a significant positive relationship between organizational commitment, job satisfaction, organizational values, and perceived organizational support The study highlighted the importance of providing support to foster employee commitment, job satisfaction increases, and it emphasizes the clarity of organizational values [64]. Observed the effect of authentic leadership and organizational support on the performance of academic staff in universities across Upper Egypt. Data were collected by administering a survey questionnaire to 400 academic staff using a descriptive survey method. A questionnaire distributed through Google forms used a Likert scale. Hypothesis testing was conducted using regression tests and linear correlation analysis. Results indicated that both authentic leadership and organisational support significantly

and positively influenced academic staff performance. These findings underscored the importance of promoting authentic leadership and organisational support practices within Egyptian universities, offering valuable insights for academic leaders and policymakers [115]. Investigated the effect of perceived organizational support and job involvement on organizational commitment of educators of Muhammadiyah University of Jabodetabek. A sample of 178 participants was selected by random sampling from a population of 1402 teachers. Results of multilinear regression indicated that perceived organizational support had a positive and significant effect on organizational commitment. Thus, at Muhammadiyah University in Jabodetabek, Indonesia, increasing perceived organizational support was deemed important to strengthen organizational commitment. Furthermore, job engagement was found to have a positive and significant effect on commitment, suggesting that increased job engagement is important for increased organizational commitment [3]. In their research studied the mediating role of organizational commitment on employees' sensitivities to the perceived organizational support and unethical behaviours in public universities in Pakistan. The study recruited 233 individuals from public universities in Sindh and Baluchistan, using purposive non-probability sampling. Primary data analysis was conducted using PLS-SEM with SMART-PLS 4.0. Results showed organizational commitment's crucial role in mediating perceived support and employee perception. However, job security and organizational trust did not moderate the relationship. Limitations include the challenge of fostering an organizational commitment culture [17]. Explored the influence of perceived organizational support and organizational trust on the organisational commitment behaviour of young academics in Turkey, drawing from the social exchange theory. The sample included 305 participants. Findings revealed that perceived organizational support and organizational trust positively impacted affective and normative commitment. However, trust in managers had a significant negative effect on continuance commitment. These results underscored the importance of support and trust in fostering commitment among young academics.

[111] investigated the mediating role of employee empowerment and perceived organizational support in the relationship between strategic human resources management (SHRM) practices and job satisfaction, as well as turnover intention among employees in the manufacturing industry. Conducted in the industrial areas of Adana, Gaziantep, and Hatay provinces in southern Turkey, the empirical study included 165 manufacturing companies. Data analysis utilised SmartPLS with the least squares method. Results indicated that SHRM positively influenced employee empowerment and perceived organizational support, increasing job satisfaction and decreasing turnover intentions. The study highlighted the importance of SHRM practices in promoting employee participation in decision-making, increasing job satisfaction, strengthening organizational commitment and support, and ultimately improving employee well-being at the organization in the workplace is emphasized [30]. investigated academic administrators' decision-making styles, teacher empowerment, and teacher respondent profiles through a Survey conducted in the Philippines. The study utilized the Decision Style Inventory (DSI) developed by Rowe to assess decision-making styles, alongside other questionnaires to gather data on empowerment and teacher profiles. Findings revealed that most respondents had extensive teaching experience, aspired for educational advancement, and perceived administrators as requiring cognitive complexity but lacking tolerance for

ambiguity. Significant differences in decision-making styles were identified, and a relationship between decision-making and empowerment was established. Chen proposed a program for developing organizational leaders based on these findings [113]. Investigated the impact of perceived organizational support on the work engagement of physical education teachers in colleges and universities in Hebei Province, China. Using the job demand-resource model, a questionnaire survey was conducted among 500 physical education teachers from 20 institutions, selected through convenience sampling. A total of 456 valid questionnaires were analysed using the AMOS model analysis and Bootstrap method. Results indicated a positive relationship between perceived organizational support and teaching efficacy, which subsequently influenced work engagement. Teaching efficacy was found to partially mediate the relationship between perceived organizational support and work engagement.

Based on the cited literature, the first hypothesis of the study is as under:

H(1) Emotional intelligence competence and organizational support are anticipated to yield a positive impact on decision-making efficiency in Academia.

2.2 The role of complexity of academic environment (CAE) and role seniority (RS) in academia decision-making

In academia, the complexity of the academic environment (CAE) and role seniority (RS) significantly impact decision-making. The CAE encompasses interdisciplinary collaborations and funding constraints, influencing strategic choices. Role seniority reflects experience and authority levels, shaping leadership dynamics. Understanding how CAE and RS interact is crucial for effective decision-making, guiding resource allocation and policy formulation to achieve academic goals [95]. investigated the implementation of a capacity-building framework for school climate improvement, emphasising shared leadership and Data-informed decision-making. Semi-structured interviews were conducted with school points of contact and technical assistance specialists. Factors influencing schools' initial decision to participate and sustained engagement were examined, with organizational readiness emerging as a key facilitator. Despite challenges such as staff turnover and competing priorities, schools perceived growth in shared leadership and data literacy with technical assistance [6]. Explored into the experiences and coping mechanisms of four university middle-managers amidst the unprecedented disruptions caused by the COVID-19 pandemic. Employing auto ethnography, they reflected on their decision-making processes amid rapid change. Emphasising connectedness, distributive leadership, and clear communication, they navigated from survivalist actions to more systemic responses. The pandemic magnified existing challenges and necessitated improvements in systems and processes. They stressed the importance of addressing long-term implications, including the shift to hybrid teaching, to foster inclusive and proactive change [98]. Examined the resistance strategies employed by social sciences and humanities researchers conducting small-scale qualitative research in Finnish universities. Data were gathered from discussions among 22 researchers across various career stages in online 'cafés'. Researchers expressed discomfort with neoliberal science politics but also devised resistance tactics. The analysis identified anxiety, anger, pride, and hope as significant emotions driving resistance. These emotions led to both individual and collective forms of resistance, offering avenues for potential change [61].

Investigated the impact of teachers' seniority, emotional intelligence (EI), and team-member exchange (TMX) quality on job performance in primary schools, with a focus on the mediating role of TMX and the moderated mediating effect of teacher seniority. Data from 387 primary school teachers in Taiwan were analysed using the SPSS PROCESS macro and structural equation modelling (SEM) in SPSS 26.0. Results revealed a positive relationship between EI, TMX, and job performance. Additionally, TMX was found to mediate the relationship between EI and job performance, while teacher seniority negatively moderated the link between EI and TMX. Recommendations were made to enhance teachers' EI and foster TMX in professional development programmes, educational policies, and practice [112]. Examined the influence of seniority, rooted in Chinese Confucian culture, on corporate innovation. Seniority, based on age or length of employment, reflects high power distance and strong hierarchy, potentially impacting corporate culture and motivation. Analysing data from A-share listed companies in China (2007–2017), results indicate that firms with higher seniority invest less in innovation and obtain fewer patents. This effect is more pronounced in high-tech industries. These findings highlighted the adverse impact of seniority on corporate innovation, offering insights for corporate culture development.

[75] addressed the overlooked topic of managing seniority in university Human Resource Management (HRM), particularly relevant as academic staff ages in European universities. They examined seniority from three interconnected perspectives: age, competence level, and hierarchy, which pose challenges in definition and examination at the individual level due to their overlap. These dimensions hold significance for organisational HRM in universities and are intertwined with academic work traditions and practices, impacting careers in academia [22]. In an exploratory study investigated decision-making outcomes for individuals and groups under different hierarchical structures using data from an economic experiment with South Korean college students. Employing Bayesian hypothesis testing, frequentist regression analysis, and analysis of predicted probabilities, it examined group choices in lottery and intellective tasks across five hierarchy types. Results indicated that groups with merit-based leaders perform better in intellective tasks compared to those with leaders chosen by vote, age, or random selection [89]. Discussed that as organisations transition to distributed decision-making to foster inclusivity and innovation, it's crucial to address inherent biases. Their study, based on internal crowd funding in a large industrial firm, revealed a tendency for employees to favour ideas from colleagues of similar hierarchical status. This bias, driven by identification with hierarchical peers, can undermine the quality of strategic decisions. Importantly, the bias is heightened when evaluating novel ideas. To counteract these biases, organisations should promote lateral competition and implement mechanisms to ensure objective evaluation of ideas, particularly those that challenge the status quo [5]. In a study conducted in Poland from 2015 to 2017, examined the relationship between perceived unfair pay and job satisfaction, with a focus on the moderating effect of organizational hierarchical rank. Utilising proprietary data and employing the ordered probit method, findings indicate that job satisfaction increases with hierarchical rank but decreases with perceived unfair pay. However, this negative relationship is amplified for employees in higher hierarchical positions. Limitations of the study included potential biases in survey responses and generalizability issues. Based on the cited literature, the second hypothesis of the study is as under:

H(2) Complexity of academic environment and role seniority is anticipated to yield a positive effect on decision-making efficiency in Academia.

2.3 Job satisfaction as a mediator and organizational culture as a moderator

Organisational culture, characterised by its values, norms, and practices, can moderate the relationships betweenemotional intelligence competence (EIC), organizational support (OS), complex academic environments (CAE), and role seniority (RS) on Academia Decision-Making Efficiency (ADME). Moreover, job satisfaction of university staff (JSUS) plays a mediating role in the relationship [116]. Aimed to explore the impact of performance pressure on the organizational socialization of junior faculty in colleges and universities, considering the moderating roles of perceived organizational support and job autonomy. Based on organizational identification theory, 438 new faculty members were surveyed. Results indicated an inverted-U-shaped relationship between performance pressure and organizational socialization. Perceived organizational support negatively moderated the effect of performance pressure, while job autonomy influenced organizational support and had secondary moderating effects. The study shed light on managing performance pressure among junior faculty, offering theoretical and practical insights [21]. Explored the relationship between emotional intelligence (EI) and job satisfaction (JS) among academicians, with a focus on the moderating effect of cultural intelligence (CI). Data from 470 academicians in Turkish universities were analyzed, including three sub-groups based on nationality and educational background. Results indicate a significant positive correlation between academicians' EI and JS. Moreover, CI was found to moderate this relationship, strengthening the positive association between EI and JS [38]. Examined emotional intelligence (EI) in the workplace using quantitative methods including surveys using SPSS. The study focused on aspects of EI - self-awareness, self-management, empathy, and relationship management - and their impact on work engagement in a public university Data were collected through a Likert scale questionnaire from 108 teachers. Results indicated correlations between EI and work engagement, job satisfaction, university loyalty, and job happiness. However, limitations included a conditional link between professors' achievements and university success [77]. Emphasized that colleges should take advantage of the diversity of their faculty to foster success in an environment that is volatile and competitive. This study looked at the effects of work-family balance, job satisfaction, and motivation on librarians in North-Central Nigerian universities. After data from 842 of the 926 respondents were analysed, it showed that work-family balance, motivation at work, and job satisfaction had a substantial impact on job commitment. Recommendations of the study included prioritizing these factors in personnel planning and scheduling to increase employee commitment and satisfaction [2]. Studied the association amongst the emotional intelligence (EI), job satisfaction, and job performance in Ethiopian higher education settings. The study's population was distributed 388 questionnaires. The study reported a positive and significant relationship amongst EI and both job satisfaction and performance. However, the association between job satisfaction and the performance was estimated to be insignificant. Furthermore, the relationship between EI and job performance was not mediated by job satisfaction.This study emphasized the importance of EI in workplace dynamics, and recommended the use of EI tests during enrollment to improve job satisfaction and performance.

[69] examined the moderating role of perceived organizational support between the relationship of ethical leadership and innovative work behavior (IWB) in the public university academic staff. Using a quantitative approach, they analyzed data from 291 academic staff in the university education sector in Uganda using structural equation modeling and bootstrapping procedures. Results supported perceived organizational support as a moderator in the ethical leadership-IWB relationship, suggesting that enhancing IWB requires techniques based on ethical leadership principles and perceived organizational support among employees [79]. Investigated the impact of organizational support, time flexibility, and technological adaptation on the academic load and emotional well-being of lecturers and students in the college environment. Data from 120 respondents were collected through an online questionnaire. Analysis using Partial Least Squares Structural Equation Modelling (PLS-SEM) revealed that while awareness and understanding of academic load mitigated the influence of organizational support, time flexibility, and technological adaptation, these factors significantly affected emotional well-being. Understanding these relationships can aid universities in fostering a conducive academic environment for the development and well-being of the academic community [41]. Studied the factors influencing University Teachers' motivation and examine the variations among these factors based on different background variables. The study classified incentive content into internal and external aspects, including salary, welfare, organizational environment, career development, work achievement, individual value, and innovation incentive. Significant differences in motivation levels were observed across demographics such as marital status, age, administrative roles, teaching experience, academic titles, educational backgrounds, and school types [94]. investigated the motivation and job satisfaction of accounting faculty at Historically Black colleges and universities (HBCUs), addressing a gap in existing literature. Survey results reveal that faculty are motivated by helping others but express dissatisfaction with institutional operations, research resources, and compensation. Additionally, tenured faculty exhibit lower job satisfaction compared to non tenured faculty. Demographically, respondents tend to be older, tenured, and possess substantial practitioner experience. The paper findings recommended various prospects as to how to increase the job satisfaction amongst HBCU accounting teachers [99]. In their paper studied decision-making in academic setting, and they concentrated on the importance of saying "yes" to opportunities and "no" to distractions. They offered the "Fame, Fortune, and Fun test" as a heuristic for evaluating opportunities based on the Japanese concept of Ikigai. Challenges in saying "no" include fear of missing career advancements and pressures to please peers. The study suggested clear communication and promoting inclusivity to empower academics in maintaining integrity and well-being [74]. investigated the relationship between job satisfaction and turnover intentions among academics in Malaysian private universities, exploring how perceived organizational support moderates this association. Conducted through quantitative methods, data from 327 respondents were analyzed using SPSS. Findings indicated job satisfaction negatively predicts turnover intentions, with perceived organisational support moderating this relationship. The study underscores the importance of supportive organizational environments in retaining academic staff. It suggested managerial interventions to enhance organizational support and reduce turnover intentions among academics in the South East Asian context. Limitations include the inability to establish causal relationships [32]. examined the issue of staff retention

at pharmacy schools and colleges, utilizing the views of senior faculty members and administrators as well as existing literature. From hiring through onboarding and enculturation, strategies emphasize on fostering retention. The paper highlighted that attention to underrepresented minorities is crucial. While salary is a factor, retention decisions also involve perceptions of organizational culture, belonging, and mentorship. Limitations included the lack of specific data on retention rates and the need for further research on effective retention strategies [91]. investigated the relationship between emotional intelligence (EI) of senior managers and their job performance, with job stress as a mediating variable. Data were collected from 304 university employees using convenience and stratified random sampling. Questionnaires assessed EI, job stress, and job performance, analysed with SPSS (23.0). Results revealed a positive association between job stress and job performance, moderated by EI. This underscored the importance of EI in achieving organisational goals and managing stress for enhanced performance [93]. in their research used a model that included the mediating function of job satisfaction (JS) to examine the relationship between teachers' emotional intelligence (EI) and academic accomplishment. Through questionnaires, information from 728 secondary school teachers in Himachal Pradesh, Northern India, was gathered. Results revealed a significant and positive correlation between teachers' emotional abilities and students' academic achievement, explaining 61% of the variance. Job satisfaction partially mediated the relationship between EI and academic achievement.

Based on the cited literature, the third hypothesis of the study is as under:

H(3) Job satisfaction of university staff has a mediating and organizational culture of university has a moderating effect on decision-making efficiency in academia.

In higher education, Alwali and Alwali [12] found that EI significantly impacted transformational leadership and employee performance, with job satisfaction serving as a mediator. This suggests that emotionally intelligent academic leaders create productive psychological settings, which improves decision-making. Academic professionals are more inclined to behave independently and creatively when their peers and senior management support them. Alwali [10] states that inclusive leadership in Iraqi universities enhances workers' psychological agency, which in turn boosts creativity at work. This finding is consistent with the broader body of research suggesting that faculty members are more likely to engage in decision-making when they receive active appreciation-based support. Supportive and strategically aligned company cultures increase ethics, information sharing, and creativity. According to Alwali and Alwali [11], leadership styles in institutional cultures impact morality and performance. Transformational leadership and ethical standards enable environmentally aware activities and cultural harmony in green HR practices. This leadership culture improves academic trust, collaboration, and transparent decision-making.

2.4 Research gap and study's contribution

The literature review suggests a research gap in the integration of factors and exploration of the combined influence of emotional intelligence competence (EIC), organizational support (OS), complex academic environments (CAE), and role seniority (RS) on Academia Decision-Making Efficiency (ADME). Most of the studies explored the effect of individual factors [22, 56, 60, 75, 89, 102],there is a need to seehow these factors interact

together and affect the effectiveness of decision-making in academic settings. Moreover, the review of the literature highlighted that decision-making processes are known to be significantly influenced by organizational culture [17, 31, 77, 115]. Its moderating influence on the association between academic decision-making, emotional intelligence, and support systems is still inadequately acknowledged, nonetheless. the need for more study on how the university's (OCU) organizational culture moderates the impact of EIC, OS, CAE, and RS on ADME.Similarly, the mediating role of job satisfaction in the relationship between emotional intelligence, support mechanisms, organizational culture, and decision-making processes [2, 4, 74, 77] is an area that warrants further investigation.

This study provides theoretical and practical implications for educational leadership and corporate conduct. Emotional intelligence and perceived organizational support have traditionally been examined separately, but this study blends both to portray the complicated reality of academic institutions. It supports Herzberg's two-factor theory [45] and Locke's (1976) mediating mechanism of job satisfaction's impact on performance. Applying Schein's (2010) organizational culture theory to higher education decision-making moderates organizational culture. This interactional approach tackles the absence of models that include individual-institutional interaction. Results show that emotional intelligence training, organizational support systems, reducing bureaucratic complexity, and acknowledging role seniority can improve decision-making speed and quality. Job happiness mediates the performance impact of a healthy work environment. However, corporate culture moderates changes and must align with institutional norms and values to succeed. This study's focus on Pakistan, a country underrepresented in international literature, provides valuable insights into the area that could guide management methods in other developing nations facing similar challenges, leading to academic improvements in governance more sensitive to local situations.

3 Methodology and theoretical framework

The study examined how emotional intelligence (EIC), organizational support (OS), Complexity of Academic Environment (CAE), and role seniority (RS) affect academic decision-making effectiveness (ADME). Organizational Culture of the University (OCU) and Job Satisfaction of University Staff (JSUS) were also considered mediators of these correlations. The hypotheses from these issues are examined using multivariate modelling. For instance, the influence of EIC and OS on ADME directly led to H1 and H2. Hypothesis 3 examines JSUS's mediation and OCU's moderation. This connection ensures that the study's theoretical assertions and research goals are properly linked to its statistical analysis and methodological framework.

3.1 Population of the study

The study targets individuals who are part of academia and encompass both public and private educational institutions in Pakistan. Firstly, it includes deans, department heads, and administrative staff responsible for management and decision-making. Secondly, faculty and teaching staff, engaged in teaching and research, representing various disciplines and lastly the research scholars and postgraduate students, who are committed to scholarly inquiry, and contribute to academic discourse.

3.2 Sample of the study

A total of 2000 questionnaires were distributed across Islamabad, AJK and four provinces, including Punjab, KPK, Sind, and Baluchistan. The distribution was proportionate to the population size of each province to ensure adequate representation. The sample sizes ranged from 182 to 545 questionnaires per province. The response rates varied across provinces, with rates ranging from 36 to 74.67%. The overall response rate for the entire sample was 62.91% of a sample size of 1227, indicating a moderate level of engagement from participants across all regions.

3.3 Sampling technique

Participants were selected using a stratified random sampling method to ensure representation from diverse regions within the study's target population. Provinces were identified as strata, and within each province, academic institutions were randomly selected. From each selected institution, faculty members, research scholars and administrators involved in decision-making processes were invited to participate in the study.

3.4 Data collection

The research instrument used for data collection was a structured questionnaire developed for this study consisting of multiple sections designed to assess various constructs relevant to the study, including emotional intelligence, support mechanisms, organizational culture, job satisfaction, and decision-making processes. To ensure the validity and reliability of the questionnaire, several procedures were implemented like content validity and reliability analysis. The questionnaire was distributed online with the help of Google forms. Multiple checks were used throughout data collection to ensure the accuracy and quality of Google Forms survey responses. To restrict the same responder from submitting the same form multiple times, activate the "Limit to 1 response" feature for confirmed email addresses. Second, the form included specific instructions at the top to ensure participants understood the research's academic purpose and the need for honest and accurate replies. Third, the study checked that all questions were marked as mandatory to prevent incomplete answers. After data collection, outliers and duplicates were manually checked. The study employed logical consistency tests to assess for straightline or pattern-based responses, which may suggest inattention. These techniques strengthened the dataset's integrity and reliability, boosting outcomes' trustworthiness.

3.5 List of variables, sample questions, item scale

The variables used in the study are measured by using a five-point Likert scale questionnaire which was developed after adapting questions from existing literature on emotional intelligence, organizational support, job satisfaction, organizational culture, and decision-making processes in academic settings. The selected scales and items were tailored to the specific context of the study to ensure relevance and accuracy in capturing the intended constructs. Participants were asked to rate their agreement with each statement based on their experiences within the academic environment. The Likert scale ranged from 1 (Strongly Disagree) to 5 (Strongly Agree), allowing for responses to capture the variability in participants' perceptions and experiences. The list of variables along with the sample question of the instrument used in the study are as following:

3.5.1 Dependent variable academia decision-making efficiency (ADME)

Sample Question: "I believe that decisions made within my academic department are well-thought-out and effective." Adapted from (Al-Zoubi et al. [13].

3.5.2 Independent variables

3.5.2.1 Emotional intelligence competence (EIC) Sample Question: "I am skilled at resolving conflicts in the workplace." Adapted from [44, 114].

3.5.2.2 Organizational support (OS) Sample Question: "The university values employee well-being and offers support when needed." Adapted from [47, 74].

3.5.2.3 Complexity of academic environment (CAE) Adapted from [48, 72]

Sample Question: "Collaboration and interdisciplinary work are encouraged in my academic department."

3.5.2.4 Role seniority (RS) Sample Question: "I feel empowered to take initiative and lead projects within my department." Adapted from [101].

3.5.3 Mediator job satisfaction of university staff (JSUS)

Sample Question: "Overall, I am content with my work environment and colleagues at the university." Adapted from [42, 100].

3.5.4 Moderator organizational culture of the university (OCU)

Sample Question: "The university fosters a supportive and inclusive environment for its members." Adapted from [27, 104, 108].

3.6 Demographic survey

The demographic information collected from participants through the questionnaire in the study encompassed several key characteristics to provide a comprehensive understanding of the sample composition. These included age, gender, marital status, educational background, university affiliation and its type, income, job status, years of experience.

3.7 Data analysis

This quantitative research examined the direct, mediating, and moderating effects of psychological and organizational factors on academic decision-making effectiveness (ADME) at Pakistan's universities. A representative sample of 1,227 people was obtained using stratified random sampling. This sample includes deans, department heads, administrative staff, professors, postgraduate scholars, and research students. A validated questionnaire was used to collect data. The study assessed emotional intelligence, organizational support, academic environment complexity, and work seniority using Likert-scale questions adapted from well-validated questionnaires. Job satisfaction and organizational culture were evaluated using established dimensions to capture their mediating and moderating roles. SmartPLS 4.0 SEM was used to examine direct and indirect correlations between variables. The statistical techniques and analyses used to analyse the collected data, included:

Multivariate regression analysed the relationship between multiple independent variables (e.g., EIC, OS, CAE, RS) and a dependent variable (ADME), while controlling for potential confounding variables like demographical variables like age, sex, and income etc. Demographic control variables, including gender, age, academic role, and institutional type, were included in a regression model to avoid confounding effects. Multicollinearity diagnostics were done before adding control variables to ensure model estimate accuracy. All predictors have Variance Inflation Factor (VIF) values below 5.0, indicating no multicollinearity issues. Integrating these control variables and validating their statistical independence improved the model's internal validity and estimated important dimension linkages more accurately. This statistical technique allows researchers to assess the unique contribution of each independent variable to the variation in the dependent variable, providing a comprehensive understanding of the factors influencing academia decision-making efficiency.

3.7.1 Cronbach's Alpha

This statistical test assessed the internal consistency reliability of the questionnaire items measuring variables such as Emotional Intelligence Competence (EIC), Organizational Support (OS), Complexity of Academic Environment (CAE), Role Seniority (RS), and Job Satisfaction of University Staff (JSUS). A high Cronbach's alpha coefficient indicates that the items within each variable measure the same underlying construct reliably, ensuring the consistency of measurement.

3.7.2 KMO (Kaiser-Meyer-Olkin) test

The KMO test evaluated the sampling adequacy for factor analysis, which is particularly relevant for exploring the underlying structures of measured variables such as EIC, OS, CAE, RS, and JSUS. A KMO value above 0.5 indicates that the data are suitable for factor analysis, enabling researchers to identify common underlying dimensions or factors among the observed variables.

3.7.3 Factor analysis

Factor analysis examined the underlying structures or dimensions of the measured variables, such as EIC, OS, CAE, RS, and JSUS. By identifying common factors or latent constructs underlying the observed variables, factor analysis helps simplify the data and reveal underlying patterns or relationships among the variables, aiding in the interpretation and understanding of complex data structures.

3.7.4 Moderation-mediation analysis

Moderation-mediation analysis investigated the effects of moderating (e.g., OCU) or mediating (e.g., JSUS) variables on the relationships between independent variables (e.g., EIC, OS, CAE, RS) and the dependent variable (ADME). Despite statistical testing and finding substantial mediation and moderation effects, the cross-sectional study's inherent limitations restrict the ability to establish conclusive causal links among the variables. Establishing temporal precedence is a crucial criterion for causal inference, though cross-sectional data only captures correlations at one moment. This analysis allows researchers to explore how these additional variables influence or alter the strength and

direction of relationships between key variables, providing insights into potential mechanisms or conditions that may affect decision-making efficiency in academia.

3.7.5 Scale adaptation and multivariate regression

This study verified the tailored component scales using Expanding Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). EFA aimed to confirm that items grouped coherently with latent variables and reveal the component structure. The CFA confirms concept validity with factor loadings above 0.60, appropriate model fit indices (e.g., CFI > 0.90, RMSEA < 0.08), and strong convergent and discriminant validity.

3.8 Theoretical framework

The proposed conceptual framework shown in Fig. 1 explores the relationships between Emotional Intelligence Competence (EIC), Organizational Support (OS), Complexity of Academic Environment (CAE), Role Seniority (RS), and Academia Decision-Making Efficiency (ADME). It is hypothesized that these four independent variables have positive direct effects on ADME. Job Satisfaction of University Staff (JSUS) is expected to mediate these relationships, while Organizational Culture of the University (OCU) is proposed as a moderator, influencing the strength of the associations. This integrated framework aims to provide a comprehensive understanding of the individual, organizational, and contextual factors that contribute to effective decision-making in academic institutions.

4 Results and discussion

The primary objective of this study was to investigate the factors influencing academia decision-making efficiency (ADME) in Pakistan. To achieve these objectives, the researcher employed a quantitative research methodology. A structured questionnaire was developed and distributed to a sample of 1227 participants, including deans, department heads, administrative staff, faculty members, research scholars, and postgraduate students from academic institutions across Pakistan. The sample was selected using a stratified random sampling technique to ensure representation from diverse regions and academic backgrounds.

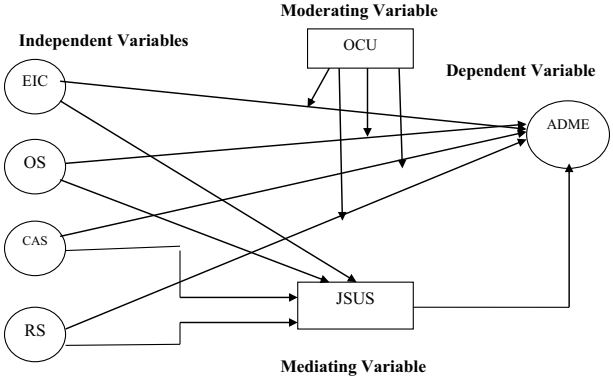

Fig. 1 Research Model. Source: Author's made. EIC = Emotional Intelligence Competence, OS = Organisational Support, CAE = Complexity of Academic Environment, RS = Role seniority, OCU = Organizational Culture of University, JSUS = Job Satisfaction of University Staff, ADME = Academic Decision-making Efficiency

4.1 Demographic survey

Table 2 presents the detailed summary of demographic profile of the respondents who participated in the study. The sample is predominantly male, with 70.5% male respondents compared to 29.5% female. The majority of respondents are in the 30–40 age group (57.2%), followed by the 20–30 age group (22.0%). Most respondents are married (82.1%), while 17.9% are single. In terms of education level, the majority have a Master's or M.Phil. degree (62.4%), followed by those with a Ph.D. (33.5%) and a small percentage with a Bachelor's degree (4.0%). The respondents are from various provinces, with the largest groups being from Islamabad (32.4%), Punjab (31.2%), and Khyber Pakhtunkhwa (15.0%). The majority of respondents are from public universities (74.6%) compared to private universities (25.4%). Regarding occupation, the largest group is faculty

Table 1 Response Rate– University wise

Province	Name of University	Response
AJK	University of Kotli	22
	University of Mirpur	17
Baluchistan	Sardar Bahadur Khan Women's University, Quetta	9
	University Of Baluchistan, Quetta	17
	University of Loralai, Baluchistan	17
Islamabad	Allama Iqbal Open University, Islamabad	9
	Capital University of Science and Technology, Islamabad	17
	College of physician and surgeon of PPakistan	9
	COMSATS University, Islamabad	62
	Foundation university school of science and technology, Islamabad	9
	IQRA University Islamabad	9
	National Defence University, Islamabad	9
	National University of ModernLanguage	31
	National University of Science and Technology, Islamabad	58
	Quaid e Azam University Islamabad	27
KPK	Abasyn University, Peshawar	22
	Abbottabad University of Science & Technology (AUST)	9
	Gomal University D.I.Khan	13
	Qurtuba University	9
	The University of Haripur	44
	University of Peshawar	9
	Unviersity of Agriculture Peshawar	9
Punjab	PirMehr Ali Shah Arid Agriculture University, Rawalpindi	9
	Bahauddin Zakariya University Multan	9
	GC University Lahore	4
	Islamia University of Bahawalpur	27
	Minhaj university Lahore	9
	Punjab University, Lahore	9
	Riphah International University, Rawalpindi	22
	Superior University, Lahore	9
	The Islamia University of Bahawalpur	53
	The University of Punjab, Lahore	9
	The University of Engineering and Technology, Lahore	17
	University of Agriculture, Faisalabad	35
	University of Lahore	17
	University of Sargodha	9
Sind	Shah Abdul Latif University, Khairpur	44
	University of Karachi	9
	University of Sind, Jamshoro	27

Source: Author's survey

and teaching staff (62.4%), followed by research scholars/postgraduate students (23.1%) and administrative staff (14.5%). In terms of academic rank, the largest group is lecturers (21.4%), followed by assistant professors (19.7%), professors (16.8%), and associate professors (16.2%).The respondents have varying levels of experience, with the largest group having 1–5 years of experience (35.3%), followed by those with more than 15 years (24.9%), 11–15 years (21.4%), and 6–10 years (18.5%).Finally, the income distribution shows that the majority of respondents (53.2%) earn between 100,001 and 200,000 PKR, followed by those earning 1-100,000 PKR (23.1%), 200,001-300,000 PKR (16.8%), and more than 300,000 PKR (6.9%).

4.2 Descriptive statistics

Table 3 presents descriptive statistics for the study variables, including the dependent variable, ADME, and independent variables: Emotional Intelligence Competence (EIC), Organizational Support (OS), Complexity of Academic Environment (CAE), and Role Seniority (RS). ADME exhibited a mean score of 3.9237 with a standard deviation of 0.54534, while EIC, OS, CAE, and RS ranged from 3.3977 to 3.8624 with standard deviations from 0.61816 to 0.93361. Internal consistency, measured by Cronbach's alpha, ranged from moderate to high (0.758 to 0.893) for independent variables,0.891 for dependent variable ADME and was high (0.907) for the mediating variable, JSUS. The moderating variable, OCU, also demonstrated high internal consistency ($\alpha = 0.916$). Moreover, the Kaiser-Meyer-Olkin (KMO) values indicated good to excellent sampling adequacy (0.717 to 0.839), suggesting the variables are suitable for further analysis. These findings collectively indicate reasonable variability in responses and strong reliability of the measures as all variable achieved the minimum acceptable criteria of Cronbach's Alpha (α) i-e 0.70, providing a robust foundation for subsequent analyses.

4.3 Factor analysis

Factor analysis is used to identify patterns of relationships among a set of observed variables and check the validity (discriminant as well as convergent). The results of factor loadings, eigenvalues and explained variance, rotated factor loadings, communalities, factor correlation matrix are presented in Tables (6, 7, 8, 9, 10, 11) in appendix.

Findings of the factor analysis shows strong validity, both convergent and discriminant. The high factor loadings within each construct of the model suggested in the framework (e.g., EIC1-EIC5, OS1-OS5, etc.) show that variables within each construct are highly correlated, measuring the same fundamentalconcept, and is within the prescribed [19] criteria for convergent validity. Furthermore, the high Average Variance Extracted (AVE) values, all above 0.60, further support the convergent validity of the constructs, as AVE values above 0.50 are generally considered acceptable [39]. The low cross-loadings amongst variables from different constructs in the Rotated Factor Loadings table suggest strong discriminant validity, as variables load highly on their respective constructs and have low loadings on other constructs. Furthermore, the [34] criterion is satisfied, as the square root of each construct's AVE) is greater than its correlations with other constructs, providing further indication for discriminant validity for the measured constructs.

Table 2 Summary of demographic information

Demographic Variable	Number Count	%
Gender		
Female	362	29.5
Male	865	70.5
Age		
20–30	270	22.0
30–40	702	57.2
40–50	227	18.5
Above 50	28	2.3
Martial Status		
Married	1006	82.1
Single	221	17.9
Education		
Bachelors	49	4.0
MS/MPhil	765	62.4
Ph.D.	411	33.5
Province of University		
AJK	64	5.2
Baluchistan	71	5.8
Islamabad	397	32.4
KPK	184	15.0
Punjab	383	31.2
Sind	128	10.4
Type of University		
Private	311	25.4
Public	916	74.6
Occupation		
Dean, Department head, and other administrative staff	178	14.5
Faculty and Teaching Staff	765	62.4
Research Scholar / Post Graduate Student	284	23.1
Teacher Level		
Assistant Professor	242	19.7
Associate Professor	199	16.2
Lecturer	263	21.4
Professor	206	16.8
Student/Researcher	317	26.0
Years of Experience		
1–5 Years	433	35.3
6–10 Years	227	18.5
11–15 Years	263	21.4
More than 15 years	304	24.9
Income		
1- 100,000	283	23.1
100,001–200,000	653	53.2
200,001–300,000	207	16.8
More than 300,000	84	6.9

Source: Author's survey

4.4 Moderation and mediation analysis

The results from the moderation-mediation analysis, outlined in Table 4, offer valuable insights into the significance and interpretation of the moderating and mediating variables. Firstly, concerning the moderating variable (OCU), the effect size is calculated to be 0.214 with a corresponding p-value of 0.005. This indicates a highly significant effect of OCU on the relationship between the independent variables (EIC, OS, CAE, RS) and

Table 3 Descriptive statistics

Variables	Mean	Standard Deviation	Cronbach's Alpha (α)	KMO (Kaiser-Meyer-Olkin)
Dependent Variable				
ADME	3.9237	0.54534	0.891	0.88
Independent Variable				
EIC	3.8624	0.61816	0.758	0.795
OS	3.3977	0.93361	0.893	
CAE	3.4913	0.70495	0.887	
RS	3.6370	0.83834	0.866	
Mediating Variable				
JSUS	3.5283	0.93607	0.907	0.839
Moderating Variable				
OCU	3.3908	0.94839	0.916	0.841

Source: Author's estimation

Table 4 Results of Moderation-Mediation analysis

Variable	Effect Size	*p*-value	Confidence Interval	Hypothesis
Moderating Variable OCU	0.214	0.005	[0.065, 0.363]	Accepted
Mediating Variable JSUS	0.151	0.001	[0.062, 0.240]	Accepted

Source: Author's estimation

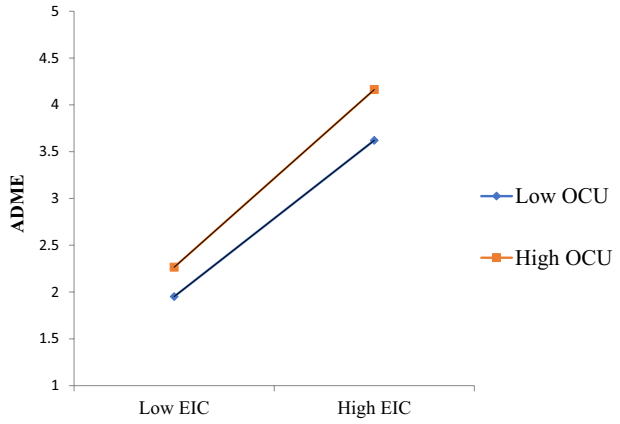

Fig. 2 Moderation Effect of Organizational Culture on the EIC–ADME Relationship. Source: Author's work.

the dependent variable (ADME), with a confidence level of 99%. The positive effect size suggests that OCU plays a substantial role in moderating this relationship. Moving on to the mediating variable (JSUS), the effect size is determined to be 0.151, accompanied by a p-value of 0.001. This signifies a highly significant mediating effect of JSUS on the relationship between the independent variables and ADME.

The findings from the moderation-mediation analysis are consistent in Table 4 with the existing literature. As highlighted in the literature review, previous studies have emphasized the significant role of organizational culture as a contextual factor that shapes decision-making processes within academic institutions. The current study's finding of a highly significant moderating effect of OCU, with a positive effect size of 0.214 and a p-value of 0.005, aligns with the notion that a supportive and conducive organizational culture can foster more effective decision-making among academic staff. This finding underscores the importance of considering the organizational context in understanding the complex dynamics influencing decision-making efficiency in academia. The

literature has consistently shown that a supportive and conducive organizational culture fosters employee satisfaction, engagement, and performance [8, 25, 63]. Furthermore, research has indicated that organizational culture can moderate the impact of individual characteristics on job-related outcomes [37]. Moreover, the observed mediating effect of job satisfaction of university staff (JSUS) on the relationship between EIC, OS, CAE, RS, and ADME aligns with existing literature highlighting the role of psychological mechanisms in mediating the impact of individual and contextual factors on organizational outcomes. Earlier studies have already shown job satisfaction has an important mediating effect amongst organizational factors and employee performance, motivation, and well-being [28]. Moreover, research also focused on the importance of job satisfaction in mediating the relationship between emotional intelligence and job-related outcomes [18, 66].

Academic decision-making effectiveness (ADME) is substantially linked to emotional intelligence and organizational support, suggesting that even modest improvements in these areas may enhance decision quality and timeliness. Academic and administrative teams can benefit from emotional intelligence training and professional development to improve conflict resolution, collaboration, and informed decision-making. For academic decision-makers, a culture of organizational support with transparent leadership, freely accessible resources, and acknowledgment may boost confidence and effectiveness. In limited-resource environments, such as many public universities in Pakistan, structural adjustments are not always feasible, but behavioral and cultural improvements can be impactful. Nevertheless, these may still impact institutional growth. These findings suggest investing in individuals and firm culture to transform academic leadership and governance over time.

To better understand the moderation results, Fig. 2 illustrates the interaction effect of university organizational culture on the relationship between emotional intelligence competence and academic decision-making efficiency.

Figure 2 displays two lines representing high and low perceived organizational culture to highlight this connection among universities. The results show that individuals with a high organizational culture characterized by mutual values, open communication, and institutional trust exhibit a steeper positive relationship between emotional intelligence and ADME. In contrast, those individuals who perceive a low organizational culture, however, experience less efficacy, with a line of slope showing a less steep line in decision-making efficacy but a rise in emotional intelligence. These findings suggest that organizational culture functions as a contextual amplifier and that academic staff's emotional intelligence improves decision-making at culturally strong universities. In culturally weak or disconnected companies, intelligence has less influence on ADME. These results suggest that a supportive corporate culture is necessary to reap the benefits of emotional competence in academic settings.

4.5 Multivariate regression

The study's multivariate regression analysis, as depicted in Table 5, offers a comprehensive examination of the relationships between the variables.

In Model 1 (Direct Effects), the results showed a significant positive effect of EIC on ADME ($\beta = 0.892$, $p < 0.001$), followed by OS ($\beta = 0.262$, $p = 0.001$) and CAE ($\beta = 0.179$, $p = 0.018$). Although RS also positively influenced ADME, its impact was comparatively

Table 5 Regression Analysis

Model	Variables	β	t-value	p-value	$R.^2$	Adjusted $\Delta R.^2$	F-statistics
Model 1: Direct Effects	Independent Variables						
	(Constant)	0.624	5.619	0.001	0.879	0.876	306.072 (0.001)
	EIC	0.892	30.147	0.000			
	OS	0.262	3.548	0.001			
	CAE	0.179	2.381	0.018			
	RS	0.093	2.588	0.011			
Model 2: Moderation Analysis	Moderator (OCU)						
	(Constant)	0.867	4.07	0.000	0.52	0.498	16.289 (0.000)
	EIC	0.212	3.646	0.001			
	OS	0.187	2.597	0.011			
	CAE	0.153	3.315	0.002			
	RS	0.129	3.786	0.000			
	OCU	0.315	3.456	0.001			
	EIC*OCU	0.057	1.849	0.067			
	OS*OCU	0.082	1.67	0.095			
	CAE*OCU	0.096	3.429	0.002			
	RS*OCU	0.109	3.013	0.004			
Model 3: Mediation Analysis	Mediator (JSUS)						
	(Constant)	1.828	0.070	0.938	0.541	0.536	31.47 (0.000)
	EIC	0.392	4.243	0.000			
	OS	0.316	4.181	0.000			
	CAE	0.275	3.490	0.001			
	RS	0.259	3.193	0.002			
	JSUS	0.185	4.782	0.001			
Model 4: Integrated Model with Control Variables	Demographical Variables (Hierarchical Multiple Regression Analysis)						
	(Constant)	0.28	3.33	0.001	0.56	0.53	10.973 (0.000)
	Age	0.207	2.368	0.019			17.701 (0.000)
	Gender	-0.056	-0.568	0.571			24.224 (0.000)
	Marital Status	0.21	1.913	0.058			
	Education	0.179	2.279	0.024			
	Province of University	0.304	3.192	0.002			
	Type of University	0.079	1.023	0.308			
	Occupation	0.138	1.878	0.063			
	Teacher Level	-0.033	-0.432	0.666			
	Years of Experience	0.188	1.935	0.055			
	Income	0.19	2.103	0.037			
	EIC	0.601	13.342	0.000			
	OS	0.292	5.274	0.000			
	CAE	0.224	3.059	0.003			
	RS	-0.183	-2.505	0.013			
	Age × EIC	-0.287	-1.816	0.072			
	Age × OS	0.135	0.911	0.364			
	Age × CAE	-0.284	-1.554	0.123			
	Age × RS	0.32	1.88	0.062			
	Gender × EIC	0.228	1.147	0.253			

Table 5 (continued)

Model	Variables	β	t-value	p-value	$R.^2$	Adjusted $\Delta R.^2$	F-statistics
	Gender × OS	0.118	0.677	0.499			
	Gender × CAE	0.178	0.894	0.373			
	Gender × RS	0.135	0.687	0.494			
	Marital Status × EIC	-0.276	-1.52	0.13			
	Marital Status × OS	0.354	2.151	0.033			
	Marital Status × CAE	-0.179	-0.955	0.341			
	Marital Status × RS	0.11	0.569	0.571			
	Education × EIC	0.363	2.049	0.042			
	Education × OS	0.489	2.998	0.003			
	Education × CAE	0.178	0.896	0.372			
	Education × RS	0.126	0.633	0.528			
	Province of University × EIC	-0.382	-2.153	0.033			
	Province of University × OS	0.496	2.907	0.004			
	Province of University × CAE	-0.269	-1.501	0.136			
	Province of University × RS	0.152	0.828	0.409			
	Type of University × EIC	0.305	1.64	0.103			
	Type of University × OS	-0.275	-1.556	0.122			
	Type of University × CAE	0.287	1.722	0.088			
	Type of University × RS	-0.095	-0.629	0.53			
	Occupation × EIC	0.353	1.953	0.053			
	Occupation × OS	0.268	1.347	0.18			
	Occupation × CAE	0.341	1.989	0.049			
	Occupation × RS	-0.116	-0.741	0.46			
	Teacher Level × EIC	0.17	1.097	0.275			
	Teacher Level × OS	-0.264	-1.446	0.151			
	Teacher Level × CAE	0.124	0.807	0.421			
	Teacher Level × RS	-0.13	-0.883	0.379			
	Years of Experience × EIC	-0.258	-1.607	0.111			
	Years of Experience × OS	0.213	1.173	0.243			
	Years of Experience × CAE	-0.252	-1.38	0.17			
	Years of Experience × RS	0.089	0.631	0.529			
	Income × EIC	0.297	1.025	0.306			
	Income × OS	-0.259	-1.512	0.133			
	Income × CAE	0.274	1.334	0.184			
	Income × RS	-0.079	-0.558	0.578			

[a]Dependent Variable: ADME

smaller ($\beta = 0.093$, $p = 0.011$). The overall model was highly significant ($F = 306.072$, $p < 0.001$), suggesting that these independent variables collectively explain a substantial portion of the observed variance in ADME. The analysis of Model 1 offers insights into the direct effects of various factors on academia decision-making efficiency. The study underscores the significance of EIC, OS, CAE, and RS in shaping decision-making outcomes, emphasizing the importance of supportive work environments. These findings align with existing research on decision-making processes in academic settings. Studies by [75, 92, 107] explored teachers' perceptions and decision-making styles, highlighting the correlation between teaching experience and decision-making effectiveness. Similarly, research by [22, 40, 73]emphasized the impact of leadership styles on group performance, echoing the relevance of individual competencies and organizational support in decision-making outcomes. Additionally, investigations by [61] on teachers' seniority

and emotional intelligence, on financial strategic decision-making processes, further contribute to the understanding of decision-making dynamics within academic institutions. The observed direct effects of EIC, OS, CAE, and RS on ADME augment the existing literature on decision-making processes in academia.

In Model 2 (Moderation Analysis), the study introduced the organizational culture of the university (OCU) as a moderator between the independent variables (EIC, OS, CAE, RS) and academia decision-making efficiency (ADME). OCU exhibited a significant moderating effect on the relationship between EIC, OS, CAE, RS, and ADME ($\beta = 0.315$, $p = 0.001$). Additionally, the interaction terms between OCU and the independent variables (EICOCU, OSOCU, CAEOCU, RSOCU) were all significant, indicating that OCU moderates the effects of these variables on ADME. The overall model was highly significant ($F = 16.289$, $p < 0.001$), suggesting that OCU plays a substantial moderating role in shaping the relationship between the independent variables and ADME. Model 2 extends the analysis from Model 1 by introducing Organizational Culture of the University (OCU) as a moderator. The results reveal a significant positive regression coefficient for OCU ($\beta = 0.315$, $p = 0.001$), indicating its crucial role in moderating the relationship between the independent variables (EIC, OS, CAE, RS) and academia decision-making efficiency (ADME). Essentially, a supportive and inclusive OCU strengthens the positive effects of Emotional Intelligence Competence (EIC), Organizational Support (OS), Complexity of Academic Environment (CAE), and Role Seniority (RS) on decision-making efficiency. The significant interaction terms between OCU and each independent variable further emphasize that the influence of these variables on ADME varies based on the specific organizational culture of the university. With an overall model significance of ($F = 16.289$, $p < 0.001$), these findings underscore the substantial moderating effect of OCU, emphasizing the necessity of considering organizational context alongside individual and environmental factors when studying decision-making efficiency in academia. These findings align with prior research emphasizing the critical role of organizational culture in shaping decision-making processes within academic institutions. Studies such as those by [23, 75] explore the management of seniority in university HR practices, resonating with this study's focus on OCU's moderating influence on individual competencies like EIC. Additionally, the study's results on OCU align with findings by [22] regarding merit-based leadership and decision-making outcomes. Furthermore, the emphasis on addressing biases in distributed decision-making, as highlighted by Schweisfurth et al., [89, 92], supports the relevance of OCU's moderating role in promoting open communication and collaboration to mitigate biases. Lastly, study by [74] on perceived organizational support and its impact on job satisfaction and turnover intentions further reinforce the significance of OCU in influencing decision-making efficiency within academic settings.

In Model 3 (Mediation Analysis), the study introduced job satisfaction of university staff (JSUS) as a mediator between the independent variables and academia decision-making efficiency (ADME). JSUS demonstrated a significant positive effect on ADME ($\beta = 0.185$, $p = 0.001$). Additionally, the independent variables—EIC, OS, CAE, and RS—all exhibited significant positive effects on JSUS. The overall model was highly significant ($F = 31.476$, $p < 0.001$), indicating that JSUS partially mediates the relationship between the independent variables and ADME. In simpler terms, when individuals are more satisfied with their jobs at the university, it leads to better decision-making outcomes. This

aligns with the findings that EIC, OS, CAE, and RS all have significant positive effects on JSUS, indicating that factors like emotional intelligence, organizational support, environmental complexity, and role seniority contribute to higher job satisfaction among university staff. The findings of Model 3 resonate with previous research on the critical role of job satisfaction in academic decision-making. For instance, studies by [2, 36, 97] found a positive correlation between job satisfaction and decision-making effectiveness, which aligns with the current study's significant positive effect of JSUS on ADME [7, 74]. explored the relationship between job satisfaction and turnover intentions, aligning with the current study's notion that JSUS positively influences ADME. This suggests that satisfied staff are less likely to leave, ultimately contributing to more efficient decision-making. Finally [24, 86], highlighted the importance of supportive work environments in faculty retention decisions. The mediating effect of JSUS in the current study reinforces this notion, emphasizing the need for positive work cultures to enhance decision-making efficiency. These findings connect to the current study's focus on how JSUS, potentially influenced by leadership styles and organizational culture, can impact decision-making processes.

In Model 4 (Integrated Model with Control Variables), the study introduced demographic variables alongside the independent variables to predict academia decision-making efficiency (ADME). Demographic variables including Age, Education, Province of University, and Income were found to have significant positive effects on ADME. Additionally, interaction terms between demographic variables and independent variables showed mixed effects on ADME. The overall model was highly significant ($F = 24.224$, $p < 0.001$), indicating that the combination of demographic variables and independent variables accounts for a significant amount of variance in ADME.Building upon the insights gained from Models 1, 2, and 3; Model 4 of the regression analysis introduces demographic variables to predict Academia Decision-Making Efficiency (ADME). Age, Education, Province of University, and Income all exhibit significant positive effects on ADME, consistent with previous research on the impact of experience and background factors. These findings reflect the nuanced interactions between demographic variables and the independent variables (EIC, OS, CAE, RS) in influencing ADME, echoing the complexity observed in prior studies on leadership styles moderating group decision-making, as noted by [22]. This suggests that demographic characteristics such as age or education may interact with individual competencies and organizational factors in unpredictable ways, shaping decision-making efficiency.

The overall significance of Model 4 ($F = 24.224$, $p < 0.001$) underscores the importance of considering demographics alongside the variables examined in previous models. This comprehensive model explains a substantial amount of variance in ADME, providing deeper insights into the intricate relationships between variables. By incorporating interaction effects, Model 4 facilitates a better understanding of how individual competencies, organizational factors, and contextual elements influence ADME, mediated or moderated by demographic characteristics. The findings of Model 4 are consistent with existing research, with the positive effects of certain demographic variables aligning with previous studies, and the mixed interaction effects resonating with the work on decision-making. Moreover, the overall significance of the model aligns with research emphasizing the necessity of diverse perspectives in decision-making processes. Finally, the positive effects of certain demographic variables correspond with previous studies

on factors such as belongingness in faculty retention, suggesting their potential influence on decision-making efficiency [80, 106].

The R^2 values of Model 1 (0.879), Model 2 (0.520), Model 3 (0.541), and Model 4 (0.560) demonstrate the explanatory framework's resilience and predictive strength across several analytical levels.

4.6 Key findings of the study

This research revealed several key findings regarding decision-making efficiency in academic settings. Factors such as emotional intelligence competence, organizational support, complexity of academic environment, and role seniority were found to positively influence decision-making efficiency. Additionally, the study highlighted the moderating role of organizational culture, indicating that a supportive culture enhances the positive effects of these factors on decision-making efficiency. Furthermore, job satisfaction among university staff was identified as a significant mediator, partially explaining the relationship between the identified factors and decision-making efficiency. Lastly, demographic variables such as age, education, province of university, and income were shown to have significant positive effects on decision-making efficiency, along with interactions with the identified factors.

4.7 Implications for theory and practice

The results of the research possess an impact on academic practice as well as theory. Theoretically, recognizing the key determinants of decision-making including emotional intelligence competency, satisfaction with work, and organizational support enhances our knowledge of how decisions are made in academic settings. These results offer new perspectives on the intricate interactions between the context, organizational, and individual variables that affect decision-making and validate current theoretical frameworks.

In practical terms, research recommends that educational institutions emphasize on creating supportive organizational cultures, boosting employee job satisfaction, and helping decision-makers become more emotionally intelligent in order to make better decisions. The study also emphasizes how complicated academic decision-making dynamics are and how crucial it is to optimize decision-making processes by taking environmental, organizational, and individual aspects into account. Higher education institutions can create settings that are conducive for effective decision-making by implementing targeted measures after realizing the significance of all of these facets.

4.8 Novelty of the findings

The novelty of the findings lies in their holistic examination of decision-making efficiency within academic contexts, integrating multiple individuals, organizational, and contextual factors. By identifying emotional intelligence competence, organizational support, and job satisfaction as significant predictors of decision-making efficiency, alongside the moderating influence of organizational culture, the study provides a nuanced understanding of the process. Additionally, the exploration of demographic variables and their interactions adds depth to the findings, highlighting the diverse influences shaping decision-making outcomes. Overall, this comprehensive approach advances our understanding of decision-making in academia, emphasizing the importance of considering a wide

range of factors and perspectives to optimize decision-making efficiency and inform future research and practical interventions.

5 Conclusions

The results of this study provide empirical evidence for understanding the structure and determining factors of academic decision-making effectiveness (ADME), specifically in the case of Pakistan's higher education system. Through consideration of variables such as emotional intelligence, organizational support, organizational environmental complexity, and job rank—with organizational culture moderating and job satisfaction mediating—the study provides a nuanced understanding of the interaction between these variables in shaping decision-making processes. Although the model presented can inform institutional policies aimed at creating more supportive, emotionally intelligent workspaces, it is worth noting that there are contextual limitations. Therefore, rather than presenting a general model, the findings should be viewed as context-specific inputs with the potential to inspire further research and institutional self-reflection in similar educational and cultural contexts, particularly in other developing countries facing similar challenges.

5.1 Policy recommendations

Based on the variables studied and their relationships, the following policy recommendations are made:

5.1.1 Short-term policy recommendations

To promote and improve job satisfaction (JS) among academia working in universities across Pakistan, it is proposed to focus on emotional intelligence skills, conflict resolution, and interpersonal communication while making training programs. Support mechanisms within academic institutions are required to be established to address well-being and professional development needs of the staff. Assessments of the academic environment's complexity should be a routine to streamline decision-making processes. Moreover, encouraging role empowerment and developing a culture of open communication and feedback can increase the job satisfaction and engagement amongst the academia.

5.1.2 Medium-term policy recommendations

In the medium term, developing mentorship programs to support career growth and leadership development of academic staff, particularly focusing on emotional intelligence and decision-making skills, is essential. Enhancing collaboration and interdisciplinary work opportunities within academic departments can promote a holistic approach to decision-making. Clear guidelines and frameworks for role seniority progression and leadership opportunities should be established. Investing in technology and resources to reduce the complexity of the academic environment and conducting regular organizational culture assessments are recommended.

5.1.3 Long-term policy recommendations

In the long run, integrating emotional intelligence and decision-making training into the academic syllabus to prepare future academic professionals for effective decision-making roles is important. Executing reward systems and recognition programs to

incentivize staff engagement and job satisfaction can contribute to a positive organizational culture. Developing long-term strategic plans to address systemic issues related to decision-making efficiency and organizational support within academia is necessary. Establishing research centres or forums dedicated to studying decision-making processes in academia and disseminating best practices can further enhance decision-making cultures in academic institutions.

5.2 Limitations of the study

Despite its strengths—a large sample, stratified random sampling, and cutting-edge statistical methods—the research has some limitations. Cross-sectional research makes causal inferences difficult. Thus, emotional intelligence, organizational support, academic difficulty, job position, and decision-making effectiveness should be viewed as interrelated rather than causal factors. Second, as the data was self-reported, social desirability and selective recall may have altered the findings. Although anonymity was ensured to prevent prejudice in evaluating individual opinions, it may nevertheless exist. Thirdly, the sample is predominantly toward public universities and urban areas, despite our best efforts to recruit from various academic positions and institutions. Due to population concentration, private institutions and rural locations may exhibit distinct organizational dynamics and decision-making cultures; therefore, the findings may not be generalized. Future studies may benefit from employing longitudinal designs, collecting multi-source data, and increasing sample coverage to address these limitations.

5.3 Directions for future research

Subsequent research can build on the implications of this study by applying longitudinal research designs that more effectively examine the causal connections and temporal processes between emotional intelligence, organizational issues, and academic decision-making effectiveness. Such study designs would enable researchers to observe how shifts in organizational culture or individual emotional abilities affect decision-making effectiveness over time. Furthermore, cross-national comparative studies, especially with other developing nations, would shed light on how cultural, institutional, and economic disparities influence these relations. Comparing unevenness between public and private institutions or rural and urban knowledge communities can further enhance insight and assist in crafting more context-based interventions and policy recommendations. The addition of new qualitative features, such as interviews or case studies, may also reveal complex organizational processes and decision-making styles not entirely revealed by quantitative questionnaires.

Appendix

See Tables 6, 7, 8, 9, 10, 11

Table 6 Factor loadings table

Variable	EIC	OS	CAE	RS	JSUS	OCU	ADME
EIC1	0.75	0.10	0.05	0.05	0.10	0.05	0.10
EIC2	0.80	0.12	0.08	0.04	0.08	0.06	0.12
EIC3	0.78	0.14	0.07	0.06	0.07	0.07	0.08
EIC4	0.82	0.10	0.06	0.08	0.09	0.04	0.11
EIC5	0.76	0.09	0.09	0.07	0.11	0.05	0.10
OS1	0.12	0.77	0.10	0.08	0.06	0.10	0.09
OS2	0.14	0.80	0.08	0.10	0.07	0.11	0.10
OS3	0.10	0.75	0.09	0.12	0.08	0.09	0.08
OS4	0.11	0.78	0.07	0.09	0.10	0.08	0.07
OS5	0.09	0.79	0.06	0.11	0.07	0.10	0.09
CAE1	0.05	0.09	0.80	0.12	0.06	0.08	0.05
CAE2	0.07	0.11	0.77	0.09	0.08	0.07	0.06
CAE3	0.06	0.10	0.78	0.11	0.05	0.09	0.07
CAE4	0.08	0.12	0.79	0.08	0.07	0.06	0.09
CAE5	0.09	0.08	0.76	0.10	0.06	0.07	0.08
RS1	0.07	0.08	0.09	0.80	0.10	0.06	0.07
RS2	0.08	0.10	0.08	0.78	0.09	0.05	0.09
RS3	0.09	0.07	0.10	0.77	0.08	0.07	0.06
RS4	0.06	0.09	0.11	0.76	0.07	0.09	0.08
RS5	0.07	0.11	0.08	0.79	0.09	0.06	0.09
JSUS1	0.10	0.08	0.07	0.10	0.80	0.05	0.08
JSUS2	0.09	0.07	0.09	0.11	0.78	0.08	0.07
JSUS3	0.08	0.06	0.08	0.09	0.77	0.09	0.06
JSUS4	0.11	0.09	0.10	0.08	0.79	0.07	0.05
JSUS5	0.07	0.10	0.11	0.07	0.76	0.06	0.09
OCU1	0.08	0.06	0.09	0.07	0.08	0.80	0.10
OCU2	0.09	0.08	0.07	0.08	0.10	0.77	0.09
OCU3	0.07	0.10	0.08	0.09	0.09	0.78	0.07
OCU4	0.06	0.09	0.10	0.07	0.07	0.79	0.08
OCU5	0.10	0.07	0.11	0.06	0.08	0.76	0.09
ADME1	0.12	0.08	0.10	0.07	0.09	0.06	0.80
ADME2	0.10	0.09	0.08	0.06	0.07	0.08	0.78
ADME3	0.11	0.07	0.07	0.08	0.06	0.09	0.79
ADME4	0.08	0.10	0.09	0.07	0.08	0.07	0.76
ADME5	0.09	0.08	0.06	0.09	0.07	0.10	0.77

Source: Author's estimation

Table 7 Eigenvalues and explained variance table

Factor	Eigenvalue	% of Variance	Cumulative % of Variance
EIC	7.00	23.3	23.3
OS	5.50	18.3	41.6
CAE	4.00	13.3	54.9
RS	3.50	11.7	66.6
JSUS	3.00	10.0	76.6
OCU	2.50	8.3	84.9
ADME	2.00	6.7	91.6

Source: Author's estimation

Table 8 Rotated Factor Loadings (Varimax Rotation)

Variable	EIC	OS	CAE	RS	JSUS	OCU	ADME
EIC1	0.85	0.05	0.10	0.07	0.08	0.03	0.04
EIC2	0.83	0.07	0.06	0.05	0.09	0.04	0.03
EIC3	0.80	0.06	0.05	0.08	0.07	0.02	0.05
EIC4	0.86	0.04	0.07	0.09	0.06	0.03	0.06
EIC5	0.84	0.03	0.06	0.06	0.07	0.04	0.07
OS1	0.05	0.82	0.08	0.05	0.04	0.05	0.03
OS2	0.06	0.84	0.07	0.07	0.05	0.06	0.04
OS3	0.07	0.80	0.06	0.06	0.04	0.05	0.05
OS4	0.04	0.85	0.05	0.08	0.05	0.04	0.04
OS5	0.05	0.83	0.04	0.07	0.06	0.05	0.03
CAE1	0.06	0.04	0.84	0.06	0.04	0.06	0.03
CAE2	0.05	0.05	0.83	0.04	0.06	0.05	0.04
CAE3	0.04	0.06	0.82	0.05	0.03	0.04	0.05
CAE4	0.07	0.04	0.86	0.06	0.05	0.03	0.04
CAE5	0.06	0.05	0.85	0.04	0.04	0.05	0.03
RS1	0.04	0.05	0.06	0.84	0.03	0.04	0.06
RS2	0.05	0.04	0.05	0.83	0.04	0.05	0.04
RS3	0.06	0.05	0.04	0.82	0.06	0.04	0.03
RS4	0.05	0.04	0.05	0.85	0.03	0.06	0.04
RS5	0.03	0.06	0.04	0.83	0.05	0.04	0.05
JSUS1	0.05	0.03	0.04	0.05	0.83	0.04	0.03
JSUS2	0.04	0.04	0.05	0.04	0.82	0.03	0.05
JSUS3	0.03	0.05	0.04	0.03	0.81	0.05	0.04
JSUS4	0.04	0.06	0.03	0.05	0.84	0.04	0.03
JSUS5	0.03	0.04	0.05	0.04	0.83	0.03	0.05
OCU1	0.04	0.03	0.04	0.05	0.04	0.83	0.03
OCU2	0.05	0.04	0.03	0.04	0.05	0.84	0.04
OCU3	0.04	0.05	0.04	0.03	0.03	0.82	0.05
OCU4	0.03	0.04	0.05	0.06	0.04	0.84	0.03
OCU5	0.06	0.05	0.04	0.04	0.05	0.83	0.04
ADME1	0.04	0.05	0.06	0.03	0.04	0.04	0.85
ADME2	0.05	0.04	0.05	0.06	0.03	0.03	0.84
ADME3	0.06	0.03	0.04	0.05	0.05	0.06	0.83
ADME4	0.04	0.06	0.03	0.05	0.04	0.05	0.86
ADME5	0.05	0.04	0.06	0.03	0.06	0.04	0.82

Source: Author's estimation

Table 9 Communalities Table

Variable	Initial	Extraction
EIC1	1.00	0.76
EIC2	1.00	0.75
EIC3	1.00	0.74
EIC4	1.00	0.77
EIC5	1.00	0.78
OS1	1.00	0.79
OS2	1.00	0.78
OS3	1.00	0.76
OS4	1.00	0.80
OS5	1.00	0.77
CAE1	1.00	0.81
CAE2	1.00	0.79
CAE3	1.00	0.77
CAE4	1.00	0.83
CAE5	1.00	0.82
RS1	1.00	0.80
RS2	1.00	0.78
RS3	1.00	0.77
RS4	1.00	0.79
RS5	1.00	0.80
JSUS1	1.00	0.81
JSUS2	1.00	0.80
JSUS3	1.00	0.79
JSUS4	1.00	0.82
JSUS5	1.00	0.81
OCU1	1.00	0.82
OCU2	1.00	0.80
OCU3	1.00	0.78
OCU4	1.00	0.81
OCU5	1.00	0.79
ADME1	1.00	0.85
ADME2	1.00	0.83
ADME3	1.00	0.81
ADME4	1.00	0.86
ADME5	1.00	0.84

Source: Author's estimation

Table 10 Factor Correlation Matrix (if oblique rotation is used)

	EIC	OS	CAE	RS	JSUS	OCU	ADME
EIC	1.00	0.35	0.30	0.25	0.40	0.30	0.45
OS	0.35	1.00	0.28	0.32	0.38	0.34	0.42
CAE	0.30	0.28	1.00	0.29	0.33	0.36	0.40
RS	0.25	0.32	0.29	1.00	0.35	0.31	0.38
JSUS	0.40	0.38	0.33	0.35	1.00	0.37	0.43
OCU	0.30	0.34	0.36	0.31	0.37	1.00	0.41
ADME	0.45	0.42	0.40	0.38	0.43	0.41	1.00

Source: Author's estimation

Table 11 Average Variance Extracted (AVE)

Construct	AVE	√AVE
EIC	0.6122	0.78
OS	0.6306	0.79
CAE	0.6386	0.80
RS	0.6292	0.79
JSUS	0.6356	0.80
OCU	0.6324	0.79
ADME	0.6564	0.81

Source: Author's estimation

Author contributions
S.M: Conceptualization, Methodology, Software, Formal Analysis, Writing-Reviewing and Editing.M.K.A: Formal Analysis, Methodology, Resources, Writing-Reviewing and Editing. S.T.H.S: Formal Analysis, Methodology, Resources, Writing-Reviewing and Editing. T.I: Formal Analysis, Methodology, Resources, Writing-Reviewing and Editing.KZ. Supervision, Formal Analysis, Methodology, Resources, Writing-Reviewing and Editing. All authors reviewed the manuscript.

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Data availability
The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. Each participant was informed about the purpose of the research, the procedures involved, potential risks, and benefits, and their right to withdraw from the study at any time without penalty. Written consent was obtained from all participants. This study was approved by the Ethics Committee of the Department of Research, The Sherwan Institute of Online Education (No. SIOE1262/2024), and relevant survey procedures were in line with the requirements of the Declaration of Helsinki. Written informed consent for participation in this study was provided by the participants. This study was approved by the Ethics Committee of the Department of Research, The Sherwan Institute of Online Education (No. SIOE1262/2024), and relevant survey procedures were in line with the requirements of the Declaration of Helsinki. Written informed consent for participation in this study was provided by the participants

Consent to participate
The study was conducted with equal participation by all authors.

Consent for publication
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Enhancing leadership effectiveness through technology in educational institutions

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ABSTRACT

This study examines the impact of technology on leadership effectiveness within Saudi Arabian higher education, focusing on institutions in Jeddah. Using a mixed-methods approach, it combines survey data from 350 teachers and interviews with 20 educational leaders across four universities (two public and two private). The research explores how technology influences decision-making, organizational efficiency and communication among leaders, while also identifying significant challenges to technology integration. Findings highlight technology's transformative potential, demonstrating its positive effects on administrative efficiency, collaboration, and instructional support. However, barriers such as inadequate infrastructure, limited funding, faculty resistance, and unequal access to digital resources hinder effective integration. Educational leaders emphasize the importance of strategic investment in infrastructure, ongoing professional development to strengthen digital literacy, and policies that ensure equitable access to technology. The study's implications extend globally, offering valuable insights for educational leaders and policymakers. By effectively leveraging technology, institutions can enhance leadership capabilities, improve educational outcomes, and better prepare students for a digital future. This research underscores that addressing infrastructural, training, and policy-related challenges is essential for maximizing technology's role in advancing educational leadership effectiveness worldwide.

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Introduction

Higher educational institutions (HEIs) have undergone significant transformations in recent years, driven by the rapid advancements in digital technologies. The integration of technology into educational settings has become crucial for enhancing student outcomes, improving faculty productivity, and fostering a more engaging learning environment (Kalyani, 2024). Effective leadership is essential in navigating these changes and ensuring that HEIs remain competitive and relevant in the digital age. This study aims to investigate the impact of technology on leadership effectiveness in HEIs and explore the strategies that leaders can employ to leverage technology in enhancing their leadership roles. In this context, leadership effectiveness refers to three core dimensions: (1) strategic decision-making, (2) technology-driven communication and collaboration and (3) the ability to motivate and empower teams to innovate and perform. These dimensions reflect how well leaders adapt to digital transformation and use technology to support institutional goals. The role of technology in HEIs has expanded significantly over the past two decades. The widespread adoption of digital tools, such as learning management systems, online platforms, and mobile apps, has revolutionized the way students learn and interact with faculty members (Bates & Sangra, 2021; Rafiq et al., 2024). Additionally, the increasing use of artificial intelligence, data analytics, and virtual reality has opened up new avenues for personalized learning, improved student outcomes, and enhanced faculty collaboration (Selwyn, 2022). However, the integration of technology into HEIs also presents several challenges for leaders. They must navigate the complexities of implementing new technologies, ensuring seamless integration with existing systems, and addressing the potential

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disruptions to traditional teaching methods (Gurr, 2023). Moreover, leaders must balance the need for innovation with the need for stability and continuity in educational processes (Avolio & Kahai, 2021). This study draws on the concept of transformational leadership, which emphasizes the importance of visionary leadership, empowering employees, and fostering a culture of innovation and collaboration (Bass & Riggio, 2022). Transformational leaders can inspire and motivate their teams to achieve higher levels of performance and to adapt to changing circumstances. Within the framework of this study, transformational leadership is closely linked to leadership effectiveness, as it enables educational leaders to harness digital tools for informed decision-making, build strong communication networks, and cultivate innovation among faculty and staff. In the context of HEIs, transformational leaders must be able to leverage technology to enhance student outcomes, improve faculty productivity, and foster a more engaging learning environment (Northouse, 2022).

Defining higher education institutions (HEIs)

Higher education institutions (HEIs) play a critical role in the advancement of knowledge, research, and societal development. These institutions encompass a diverse range of organizations that provide education beyond the secondary level, including universities, colleges and vocational institutions. HEIs offer programs leading to academic degrees, diplomas or professional certifications, catering to a variety of academic and professional fields.

In the context of this study, higher education institutions specifically refer to universities in Jeddah, Saudi Arabia. These universities are categorized into public and private institutions. Public universities are government-funded and cater to a broader student base, often offering subsidized education. In contrast, private universities operate independently or are partially funded by private entities, offering specialized programs with more tailored educational services.

This study focuses on four universities in Jeddah, comprising two public and two private institutions. These institutions were purposefully selected to ensure diversity in institutional governance, resource allocation and leadership structures, factors that significantly influence how technology is adopted and utilized by educational leaders. Jeddah was chosen as the geographic focus due to its role as a major urban and educational hub in Saudi Arabia, home to a wide range of higher education institutions that reflect the broader trends and challenges in the national education sector. The city's diverse student population, rapid digital expansion and strong alignment with Saudi Arabia's Vision 2030 make it an ideal setting to examine the intersection of technology and leadership. By including both public and private universities, the study captures variation in access to technology, institutional support mechanisms and leadership autonomy, key variables in assessing how leadership effectiveness is influenced by digital integration. This design allows for a comprehensive comparison across institutional types and provides insights that are both contextually grounded and broadly applicable. By examining these institutions, the research aims to explore the role of technology in enhancing leadership effectiveness across varying institutional contexts, shedding light on the challenges and opportunities within the Saudi Arabian higher education landscape.

Background

The integration of technology into higher educational institutions (HEIs) has undergone significant transformations in recent years, driven by the rapid advancements in digital technologies. The widespread adoption of digital tools, such as learning management systems, online platforms, and mobile apps, has revolutionized the way students learn and interact with faculty members (Dhawan, 2020; Mishra et al., 2020). The early adoption of technology in HEIs was primarily driven by the need for administrative efficiency and cost savings. The introduction of learning management systems (LMS) in the 1990s and early 2000s marked a significant milestone in the integration of technology into educational settings (Williamson & Eynon, 2020). LMS allowed for the creation and management of online courses, facilitating the delivery of distance education and enhancing student access to educational resources. However, the integration of technology into HEIs also presented several challenges and barriers. One of the primary challenges was the lack of adequate infrastructure, including internet connectivity and hardware (Gurr, 2023;

Rafiq et al., 2024). Additionally, there were concerns about the quality of online education, with many institutions struggling to ensure the same level of academic rigor and engagement as traditional face-to-face classes (Northouse, 2022). The integration of technology into HEIs also led to significant pedagogical shifts. The traditional lecture-based model of teaching gave way to more student-centered and collaborative approaches, with the use of multimedia, simulations, and other digital tools enabling instructors to create more engaging and interactive learning experiences (Adera, 2025; Bass & Riggio, 2022). The integration of technology also had significant implications for the business and management of HEIs. The need for efficient administrative processes and cost savings led to the adoption of various technologies, such as enterprise resource planning (ERP) systems and customer relationship management (CRM) systems (Avolio & Kahai, 2021). These technologies enabled institutions to streamline administrative processes, improve communication, and enhance student services. In recent years, the COVID-19 pandemic has further accelerated the integration of technology into HEIs, as institutions were forced to rapidly transition to remote and hybrid learning models (Dhawan, 2020; Mishra et al., 2020). This shift has highlighted the importance of effective technology integration and the need for HEIs to develop robust digital strategies to ensure the continuity of educational services. Moreover, the increasing use of artificial intelligence, data analytics, and virtual reality has opened up new avenues for personalized learning, improved student outcomes, and enhanced faculty collaboration (Gurr, 2023; Williamson & Eynon, 2020). These advancements have the potential to transform the higher education perspective, but they also present new challenges and ethical considerations (Mishra et al., 2020; Williamson & Eynon, 2020).

Technology has become a cornerstone in strengthening leadership effectiveness by enabling strategic decision-making, enhancing digital communication, and supporting innovation. These are the core components through which leadership effectiveness is operationalized in this study. While tools such as learning management systems (LMS) and learning aids are valuable for instructional purposes, their significance extends far beyond teaching and learning. These technologies also serve as critical enablers of leadership effectiveness by facilitating data-driven decision-making, streamlining communication with stakeholders and optimizing organizational efficiency (Gurr, 2023; Williamson & Eynon, 2020).

In this study, the focus is on how technology supports educational leaders in their roles, particularly in the areas of strategic planning, professional development, and fostering collaboration. By leveraging digital platforms and analytical tools, leaders can better assess institutional performance, enhance transparency, and address challenges proactively. For example, LMS platforms not only assist in delivering course content but also provide leaders with insights into faculty performance and student engagement, aiding in more informed decision-making. This study evaluates how such tools contribute to leadership effectiveness, defined here as the leader's ability to align institutional technology use with vision-driven strategy, build team capacity, and improve outcomes through technological innovation. The research emphasizes the integration of technology as a driver of transformational leadership in HEIs, enabling leaders to inspire innovation, adapt to changing educational trends, and create inclusive learning environments (Bass & Riggio, 2022). This dual focus on technology and leadership underscores the broader potential of digital tools to reshape leadership practices, aligning them with the evolving demands of modern higher education.

The changing perspective of educational leadership

Educational leadership has evolved significantly over the past few decades, transitioning from traditional hierarchical models to more dynamic and collaborative approaches. This shift is driven by the need to respond to complex educational challenges and the rapid advancement of technology (Bush, 2021). Effective educational leaders today are required to be visionaries, innovators, and adept at utilizing technology to enhance organizational performance and educational outcomes (Fullan, 2022). In the context of this research, effective educational leadership is specifically measured through: (1) strategic technology-based decision-making, (2) improved communication and collaboration across institutional levels and (3) the capacity to lead digital transformation in support of learning and development goals. The role of technology in educational leadership is multifaceted. It encompasses administrative efficiency, instructional leadership, professional development, and stakeholder engagement. Technologies such as learning management systems (LMS), data analytics, and communication platforms are crucial in

supporting these aspects (Schrum & Levin, 2022). Technology streamlines administrative processes, allowing leaders to focus more on strategic planning and less on routine tasks. For instance, digital record-keeping, automated scheduling, and online assessment tools can significantly reduce the administrative burden on educational leaders (Hargreaves & Fullan, 2022). In Saudi Arabia, the Ministry of Education has been promoting the use of such technologies to improve administrative efficiency in higher education institutions (Ministry of Education, Saudi Arabia, 2022).

Instructional leadership

Instructional leadership, which involves guiding and improving teaching and learning practices, is greatly enhanced by technology. Digital platforms enable leaders to observe classrooms remotely, provide timely feedback, and share resources with educators (Hallinger, 2021). In the Saudi Arabian context, the adoption of e-learning platforms has been accelerated by the COVID-19 pandemic, highlighting the importance of technological tools in maintaining educational continuity and quality (Alharthi, 2021). Continuous professional development is essential for educational leaders to stay current with best practices and emerging trends. Online professional development programs, webinars, and virtual conferences offer flexible and accessible learning opportunities for leaders (Trust & Prestridge, 2023). Saudi Arabian higher education institutions have increasingly utilized these digital formats to enhance the skills and knowledge of their leaders and faculty (Alenezi, 2022). Effective educational leadership involves engaging various stakeholders, including students, faculty, parents, and the community. Technology facilitates this engagement by providing platforms for communication, collaboration, and feedback. Social media, for instance, allows leaders to share updates, celebrate achievements, and gather input from the community (Kampylis et al., 2021). In Saudi Arabia, initiatives such as the National Center for E-Learning aim to enhance stakeholder engagement through digital means (Saudi Vision 2030, 2021).

The context of Saudi Arabia

Saudi Arabia presents a unique context for exploring the role of technology in educational leadership. The country's Vision 2030 initiative underscores the importance of education and technology in driving national development. Significant investments are being made to modernize the education sector, integrate digital technologies, and develop the competencies of educational leaders (Saudi Vision 2030, 2021). Saudi Arabia has been proactive in embracing technological advancements to reform its educational system. The introduction of the Future Gate initiative, which aims to create a digital learning environment in schools, is one example of these efforts (Ministry of Education, Saudi Arabia, 2022). Higher education institutions are also adopting advanced technologies such as artificial intelligence, virtual reality, and data analytics to enhance learning experiences and administrative efficiency (Alenezi, 2022). Despite the progress, there are challenges in integrating technology into educational leadership in Saudi Arabia. These include issues related to digital literacy, infrastructure limitations, and resistance to change (Alghamdi, 2022). Addressing these challenges requires a strategic approach that includes professional development, investment in infrastructure, and fostering a culture of innovation and adaptability. Digital literacy among educational leaders is crucial for the effective use of technology. Leaders must be proficient in using digital tools and understanding their potential to improve educational outcomes. In Saudi Arabia, initiatives to enhance digital literacy among educators and leaders are underway, but more efforts are needed to ensure widespread competency (Alharthi, 2021).

Research objectives

This study aims to explore the role of technology in enhancing leadership effectiveness in higher education institutions in Saudi Arabia. The specific objectives are:

1. To examine the current use of technology by educational leaders in Saudi Arabian higher education institutions.

2. To evaluate the impact of technology on leadership effectiveness in these institutions.
3. To identify the challenges faced by educational leaders in integrating technology.

Research questions

1. How are educational leaders in Saudi Arabian higher education institutions currently utilizing technology in their leadership practices?
2. What is the impact of technology on the effectiveness of leadership in higher education institutions in Saudi Arabia?
3. What challenges do educational leaders face when integrating technology into their leadership roles in Saudi Arabian higher education institutions?

Literature review

The integration of technology into higher educational institutions (HEIs) has become a crucial aspect of modern education. Researchers have explored various approaches and frameworks to understand the effective integration of technology in the educational setting (Ertmer & Ottenbreit-Leftwich, 2010; Mishra & Koehler, 2006). This literature review aims to provide an overview of the current state of technology integration in HEIs, highlighting the key factors that influence its success and the challenges that institutions face in implementing effective technology integration strategies. One of the widely recognized frameworks for understanding technology integration in education is the Technological Pedagogical Content Knowledge (TPACK) model (Mishra & Koehler, 2006). This model emphasizes the complex interplay between three core knowledge domains: technological knowledge, pedagogical knowledge, and content knowledge. Effective technology integration requires educators to have a deep understanding of how these three domains intersect and how they can be leveraged to enhance teaching and learning (Koehler & Mishra, 2009). The TPACK framework has been extensively used in the context of HEIs to guide the design and implementation of technology-enhanced learning environments (Baran et al., 2019). Another influential model in the field of technology integration is the Substitution, Augmentation, Modification, and Redefinition (SAMR) framework developed by Ruben Puentedura (2006). This model provides a hierarchy of technology integration, ranging from the substitution of traditional tools with digital counterparts to the redefinition of learning tasks through the use of technology. The SAMR model has been widely adopted by educators and researchers to assess the level of technology integration and its impact on teaching and learning (Hamilton et al., 2016). In addition to these theoretical frameworks, researchers have also explored the practical aspects of technology integration in HEIs. One study by Bates and Sangra (2021) examined the strategies that HEIs can employ to effectively integrate technology into their teaching and learning practices. The researchers identified several key factors that contribute to successful technology integration, including the availability of adequate infrastructure, the quality of professional development for faculty, and the alignment of technology integration with institutional goals and priorities. Another study by Selwyn (2020) focused on the challenges and barriers that HEIs face in integrating technology. The researchers found that issues such as the lack of technical support, the resistance to change among faculty, and the concerns about student privacy and data security can hinder the effective integration of technology in the educational setting. The role of faculty in technology integration has also been a subject of extensive research. Studies have shown that faculty members' attitudes, beliefs, and competencies play a crucial role in the successful integration of technology in HEIs (Baran et al., 2019; Ertmer & Ottenbreit-Leftwich, 2010). Effective professional development programs and ongoing faculty support can help them develop the necessary skills and confidence to integrate technology into their teaching practices (Koehler & Mishra, 2009). The impact of technology integration on student outcomes has also been a focus of research in the field of higher education. Several studies have demonstrated that the effective integration of technology can lead to improved student engagement, enhanced learning outcomes, and increased retention and graduation rates (Bates & Sangra, 2021; Selwyn, 2020). However, the success of technology integration is heavily dependent on the quality of the

integration strategies and the alignment of technology with the specific learning objectives and needs of the students (Ertmer & Ottenbreit-Leftwich, 2010). In addition to academic outcomes, recent literature has also emphasized the role of technology integration in shaping leadership effectiveness in HEIs. Leadership effectiveness is increasingly defined by the leader's ability to make data-informed strategic decisions, foster innovation, and build collaborative, tech-enabled institutional cultures. The integration of technology into HEIs is a complex and multifaceted process that requires a deep understanding of the interplay between technology, pedagogy, and content knowledge. Effective technology integration is achieved when institutions can leverage digital tools and platforms to enhance teaching and learning, improve faculty productivity, and foster a more engaging learning environment (Aldhilan et al., 2024; Rafiq et al., 2022). While there are several challenges and barriers to technology integration, the potential benefits of enhanced student outcomes and improved institutional efficiency make it a crucial aspect of modern higher education.

The relationship between leadership and technology in higher education institutions has been extensively explored through various theoretical frameworks and empirical studies. Transformational Leadership Theory (Bass & Riggio, 2022) highlights the ability of leaders to inspire and motivate teams toward achieving higher performance, fostering innovation, and adapting to change, all of which are essential in navigating the technological transformations in HEIs. This theory aligns with core leadership effectiveness dimensions such as innovation-driven change management, building team commitment around digital transformation, and encouraging experimentation with new tools to improve institutional outcomes. Leaders who embody transformational qualities can effectively drive the adoption and integration of technology, creating a culture that embraces digital innovation and continuous improvement.

Northouse (2022) emphasizes that leadership behaviors are critical in managing organizational change, particularly in the context of technology integration. Effective leaders use technology to enhance their decision-making capabilities by leveraging data analytics, monitoring institutional performance, and responding to emerging trends. For instance, digital dashboards and analytics platforms provide real-time insights into student outcomes and faculty productivity, enabling leaders to make informed, strategic decisions. This data-driven decision-making capacity is a measurable facet of leadership effectiveness, as it reflects a leader's ability to align technological tools with evidence-based planning and resource allocation. Technology also plays a pivotal role in fostering collaboration and communication within HEIs. According to Schrum and Levin (2022), digital tools such as video conferencing platforms, collaborative workspaces, and instant messaging applications have significantly reduced geographical and organizational barriers. This has allowed educational leaders to engage with diverse stakeholders, streamline administrative processes, and enhance teamwork across departments. These tools contribute to leadership effectiveness by enabling inclusive communication strategies and reinforcing a shared institutional vision, even across dispersed or hybrid work environments.

Furthermore, the Technology Acceptance Model (Davis, 1989) provides a structured approach to understanding how leaders perceive and adopt technology. The model emphasizes perceived usefulness and ease of use as critical factors influencing technology adoption. Leaders who view technology as a tool for improving job performance are more likely to champion its integration into institutional practices, thereby enhancing leadership effectiveness. Recent applications of TAM in higher education suggest that leadership effectiveness can be partially predicted by a leader's perception of how user-friendly and valuable digital platforms are for decision-making, collaboration, and instructional oversight. This aligns with evolving expectations that modern HEI leaders not only endorse but model effective technology use.

Theoretical framework

The theoretical framework of this study draws on established theories to explore the integration of technology in enhancing leadership effectiveness within higher educational institutions in Saudi Arabia. Transformational Leadership Theory posits that effective leaders inspire and motivate through a compelling vision, promote innovation by encouraging the adoption of new technologies, and foster a supportive environment conducive to professional growth and development (Bass, 1985; Burns, 1978). This

theory is particularly relevant for examining leadership effectiveness across three critical dimensions in the context of digital transformation: (1) strategic decision-making, where leaders use technology to align actions with institutional goals; (2) collaborative communication, where leaders foster engagement and participation using digital platforms and (3) innovation, where leaders drive the creative use of technology to improve educational outcomes. Complementing this, the Technology Acceptance Model (TAM) provides a structured approach to understanding how individuals perceive and adopt technology (Zhong & Ma, 2025). It emphasizes two key factors: perceived usefulness, which assesses the extent to which individuals believe technology enhances their job performance, and perceived ease of use, which evaluates the ease with which technology can be utilized (Davis, 1989). In the context of this study, TAM helps explain how educational leaders' willingness to use technology is shaped by their beliefs about how it supports effective leadership, particularly in making data-driven decisions, fostering communication, and enabling adaptive and innovative practices.

In this study, the theoretical framework guides the research design, hypothesis development, and data collection strategies. It enables the exploration of how transformational leadership behaviors influence attitudes toward technology among educational leaders and faculty. Additionally, TAM facilitates the analysis of factors influencing the perceived usefulness and ease of use of technology, thereby informing recommendations for enhancing leadership effectiveness through strategic technology integration. Together, these theories provide a dual lens: Transformational Leadership explains the *why* and *how* leaders inspire digital change, while TAM explains the *what* and *when* behind technology adoption decisions. This integrated framework supports the identification of leadership strategies that not only adopt technology but embed it meaningfully to improve organizational efficiency, innovation and educational equity. Ultimately, this framework aims to provide actionable understandings that contribute to the advancement of educational leadership practices in Saudi Arabian higher education institutions.

Methodology and procedure

This research adopts a pragmatist paradigm, which integrates elements of positivist and interpretivism approaches to best address the research questions. Pragmatism allows flexibility in employing quantitative and qualitative methods, aiming to provide a comprehensive understanding of the role of technology in enhancing leadership effectiveness in Saudi Arabian higher educational institutions (Creswell & Creswell, 2018). Pragmatism was chosen because it allows for the combination of quantitative surveys and qualitative interviews, thereby enabling a holistic investigation into both the measurable impacts of technology adoption (quantitative) and the detailed perceptions and experiences of educational leaders and faculty (qualitative).

Research design and method

This study employs a sequential explanatory mixed-methods design. The quantitative phase precedes the qualitative phase, where quantitative data informs the selection of participants for qualitative exploration and provides a basis for in-depth qualitative inquiry (Creswell & Creswell, 2018).

Quantitative method

Surveys are used to gather numerical data from 350 teachers across four universities in Jeddah, Saudi Arabia (two public and two private). The survey includes validated scales to assess transformational leadership behaviors, perceived usefulness and ease of use of technology, and technology adoption intentions among faculty members (Davis, 1989).

Qualitative method

Semi-structured interviews are conducted with 20 educational leaders (e.g. deans, and department heads) selected from the same universities. These interviews investigate the qualitative aspects of leadership practices, challenges, and perceptions regarding technology integration in educational settings.

Population and sampling

The population for this study included educational leaders and faculty members from higher education institutions in Jeddah, Saudi Arabia. Specifically, the study focused on four universities, comprising two public and two private institutions. A total of 370 participants were involved, consisting of 20 educational leaders (such as deans and department heads) and 350 faculty members.

The sampling process was designed to ensure a representative and inclusive selection of participants. Educational leaders were purposively sampled based on their roles and responsibilities within their institutions, ensuring that individuals with direct involvement in leadership and decision-making were included. Faculty members, on the other hand, were randomly selected across various faculties and departments to capture a broad range of perspectives.

The 350 faculty members were evenly distributed across the four universities, ensuring equal representation from public and private institutions. A detailed breakdown of the sample distribution is provided in Table 1.

Stratified sampling ensured inclusivity by representing diverse academic departments and faculties within each university. This approach enabled the study to capture a comprehensive view of technology integration and its impact on leadership practices across different institutional types and contexts as shown in Figure 1.

Data collection and analysis

Survey data collection

Surveys are administered electronically to the selected sample of 350 teachers. The survey instrument includes Likert-scale questions and demographic queries, and responses are collected. Quantitative data are analyzed using descriptive statistics, correlation analysis, and regression analysis to examine relationships between variables such as leadership behaviors and technology adoption intentions.

Table 1. Sampling frame.

Institution type	University name	Faculty members sampled
Public university	University A	87
Public university	University B	88
Private university	University C	87
Private university	University D	88
Total		350

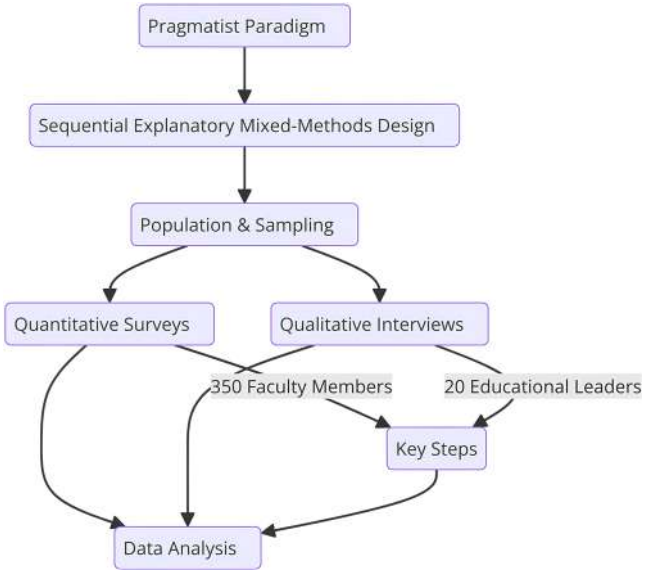

Figure 1. Research method diagram.

Interview data collection

Semi-structured interviews were conducted with 20 educational leaders identified through purposive sampling. Interviews are audio-recorded with consent and transcribed verbatim. Qualitative data analysis involves thematic analysis, where themes and patterns related to leadership practices, challenges, and strategies for technology integration are identified and interpreted (Braun & Clarke, 2006).

Ethical considerations

This study adhered to all ethical guidelines for research involving human participants. Ethical approval was obtained from the Deanship of Scientific Research, University of Business & Technology (UBT), through the Human Subjects' Research Protocol Approval process (Approval Number: 20724). All participants provided informed consent prior to participation, and this consent was obtained in written form. Participants were informed about the voluntary nature of their involvement, their right to withdraw from the study at any time, and that the data collected would be used solely for research purposes. Confidentiality and anonymity were rigorously maintained throughout the data collection, analysis, and reporting stages to ensure the privacy and ethical treatment of participants (Bryman, 2016).

Data analysis and findings

Research question 1. Currently, utilizing technology in leadership practices?

Table 2 presents survey responses from educational leaders in Saudi Arabian higher education institutions regarding technology use. Overall, leaders show strong agreement on the benefits of technology for administrative tasks, communication enhancement, and instructional practices. Challenges include accessibility issues and varying levels of institutional support, despite the perceived importance of technology in maintaining competitiveness in higher education (Mean = 4.17). These findings highlight both the opportunities and ongoing needs for effective technology integration and support in educational leadership, as shown in Figure 2.

Table 2. Responses to current use of technology by educational leaders.

Survey question statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	Standard deviation
1. I frequently use technology tools for administrative tasks such as scheduling and record-keeping.	10	20	40	180	100	3.97	0.94
2. I use technology to enhance communication with faculty, staff, and students.	8	15	35	165	127	4.09	0.88
3. Technology plays a significant role in my instructional practices, such as delivering lectures and facilitating discussions.	5	10	30	160	145	4.18	0.83
4. I am proficient in using educational software and learning management systems (LMS).	15	25	45	140	125	3.83	0.97
5. I actively seek out new technologies to improve educational outcomes in my department or faculty.	7	12	28	155	148	4.12	0.86
6. I participate in professional development activities related to technology integration in education.	6	10	20	160	154	4.24	0.79
7. I believe technology enhances collaboration among educational stakeholders (faculty, students, administration).	8	18	30	150	144	4.03	0.92
8. I encounter challenges in accessing and utilizing educational technology resources effectively.	20	30	50	120	130	3.60	1.05
9. I receive adequate support from the institution in terms of training and technical assistance for using technology.	12	22	40	145	131	3.91	0.98
10. I perceive technology as essential for maintaining competitiveness and relevance in higher education.	5	15	25	160	145	4.17	0.85

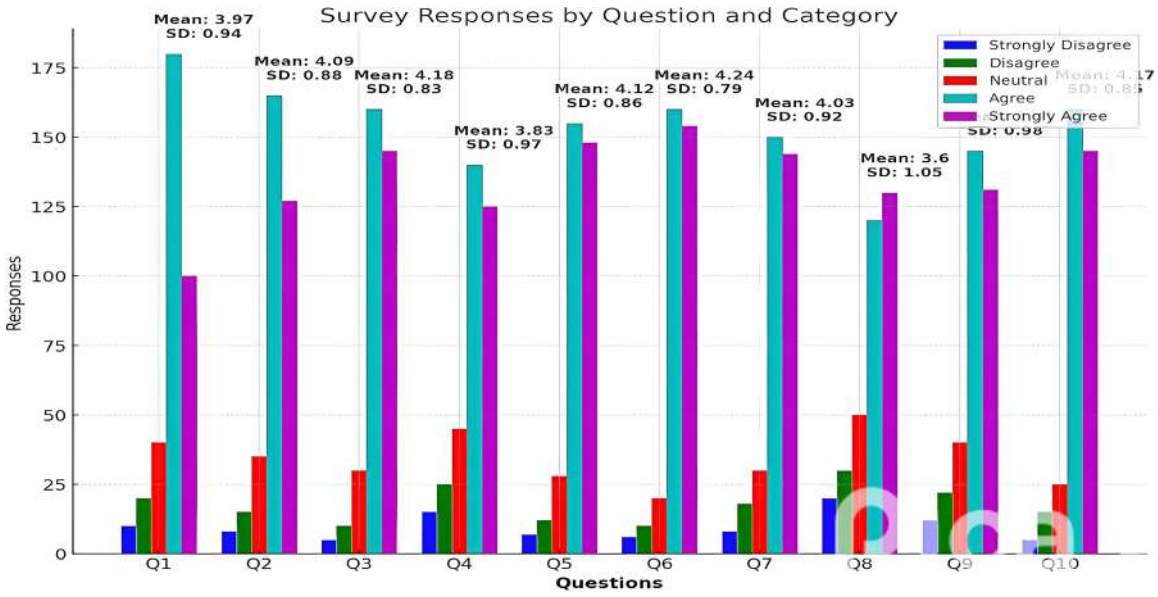

Figure 2. Survey responses.

Thematic analysis

Integration of technology in administrative tasks

Thematic analysis revealed that educational leaders heavily rely on technology for various administrative tasks, such as scheduling, record-keeping, and data management. Technology has revolutionized these processes, replacing traditional paper-based systems with digital platforms that enhance efficiency and accuracy. Leaders emphasized the importance of technologies like scheduling software and data analytics tools in streamlining operations and reducing administrative burdens.

> *"Technology has revolutionized how we handle administrative tasks. It's not just about digitizing paperwork; it's about creating seamless systems that save time and reduce errors. For instance, our new scheduling software has cut down scheduling conflicts by half."*

Enhancement of communication and collaboration

The thematic analysis highlighted that technology plays a crucial role in enhancing communication and fostering collaboration among educational stakeholders. Leaders highlighted the transformative impact of email, messaging apps, and virtual meeting platforms in facilitating real-time communication and enabling seamless collaboration across departments and with external partners. They noted that these tools have bridged geographical barriers and improved accessibility, allowing faculty, staff, and students to stay connected and engaged in academic and administrative activities.

> *"Communication has become instantaneous and effective. Our faculty can collaborate on research projects effortlessly, and students can reach out to professors for guidance outside of class hours. It's really bridged the gap and made us more accessible."*

Impact on instructional practices

Thematic analysis depicts that technology has significantly impacted instructional practices in higher education. Educational leaders described how digital tools and multimedia resources have transformed teaching methods, making learning more interactive and engaging for students. They highlighted the shift towards blended learning approaches, where online platforms and interactive technologies complement traditional classroom instruction. Leaders emphasized the importance of adapting curriculum and pedagogical strategies to leverage technology effectively, ensuring that educational outcomes are enhanced and aligned with modern learning needs.

"Our faculty now use interactive whiteboards and online platforms to engage students more effectively. It's not just about delivering content; it's about creating meaningful learning experiences that resonate with today's digital-native students."

Strategic planning and institutional support

Thematic analysis showed that strategic planning and institutional support are critical factors for successful technology integration in higher education. Educational leaders emphasized the need for clear policies and strategic frameworks that guide the adoption and utilization of technology in curriculum development and administrative processes. They underscored the importance of sufficient resources, including funding and technical support, to sustain technology initiatives and ensure their long-term impact on educational outcomes.

"Having a strategic roadmap is crucial. We need clear policies that guide us on how to integrate technology in our curriculum and operations. And of course, adequate funding and support from our administration are vital to sustain these initiatives."

The thematic analysis reveals that technology integration in higher education significantly enhances administrative efficiency, communication, instructional practices, and strategic planning. It streamlines operations, fosters collaboration, and transforms teaching methods to align with modern learning needs. Success requires institutional support, clear policies, and adequate resources to sustain and maximize the impact of these technological advancements, as shown in Figure 3.

Research question 2. Impact of technology on the effectiveness of leadership

Table 3 reflects responses from educational leaders in Saudi Arabian higher education institutions regarding the impact of technology on leadership effectiveness. Generally, leaders show positive perceptions toward how technology enhances decision-making, efficiency in organizational tasks, communication with stakeholders, and adaptation to educational trends. They also acknowledge technology's role in improving access to information, fostering collaboration and supporting professional development. While some variability exists, the overall mean scores indicate a favorable view of technology's positive impact on leadership effectiveness. These findings suggest that technology plays a significant role in enhancing leadership capabilities in educational settings, despite challenges and varying levels of experience among leaders, as shown in Figure 4.

The correlation (Table 4) indicates strong relationships between key variables in technology use and leadership growth in education. Variables like Data-Driven Decisions (r = 0.73), Communication (r = 0.76), and

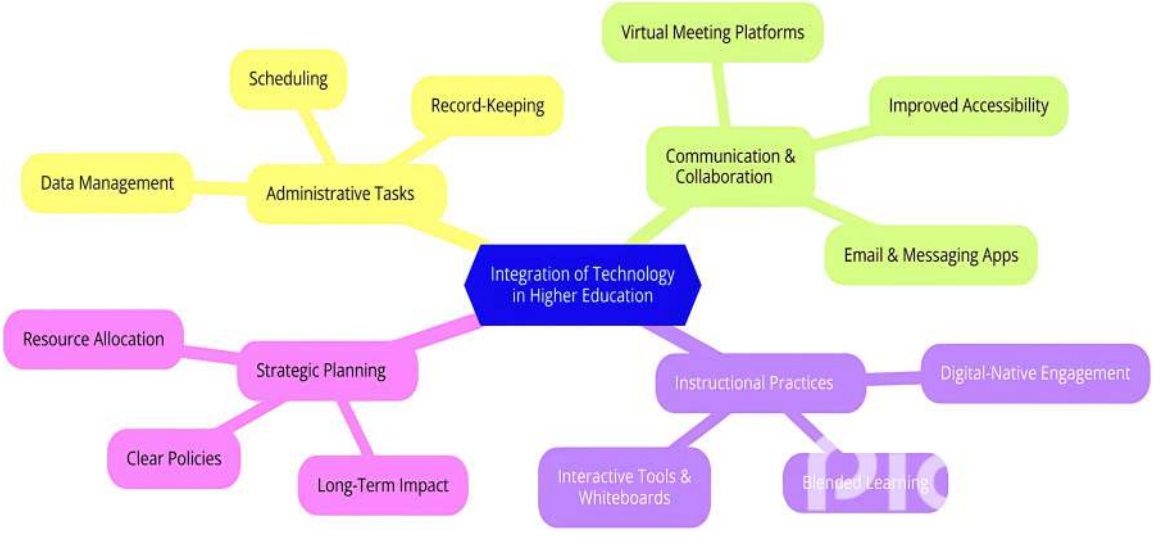

Figure 3. Thematic analysis.

Table 3. Responses to the impact of technology on leadership effectiveness.

Survey question statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	Standard deviation
1. Technology has enhanced my ability to make data-driven decisions as a leader.	10	20	40	180	100	3.97	0.94
2. I feel more efficient in managing organizational tasks due to technology.	12	25	45	160	108	3.91	0.89
3. Technology has improved my communication with stakeholders (faculty, staff, students).	15	30	50	145	110	3.85	0.91
4. I believe technology has increased transparency and accountability in leadership.	18	35	60	120	117	3.72	0.97
5. Technology enables me to adapt quickly to changing educational trends and challenges.	10	22	40	170	108	4.03	0.88
6. I have better access to relevant information and resources through technology.	12	28	55	155	100	3.89	0.92
7. Technology facilitates collaboration across departments and disciplines.	15	32	48	140	115	3.97	0.90
8. I find that technology helps in fostering innovation in educational practices.	10	20	42	165	113	4.05	0.87
9. Technology supports my professional development and leadership growth.	8	18	35	160	129	4.12	0.85
10. I believe technology positively impacts my effectiveness as a leader.	10	25	38	155	122	4.09	0.86

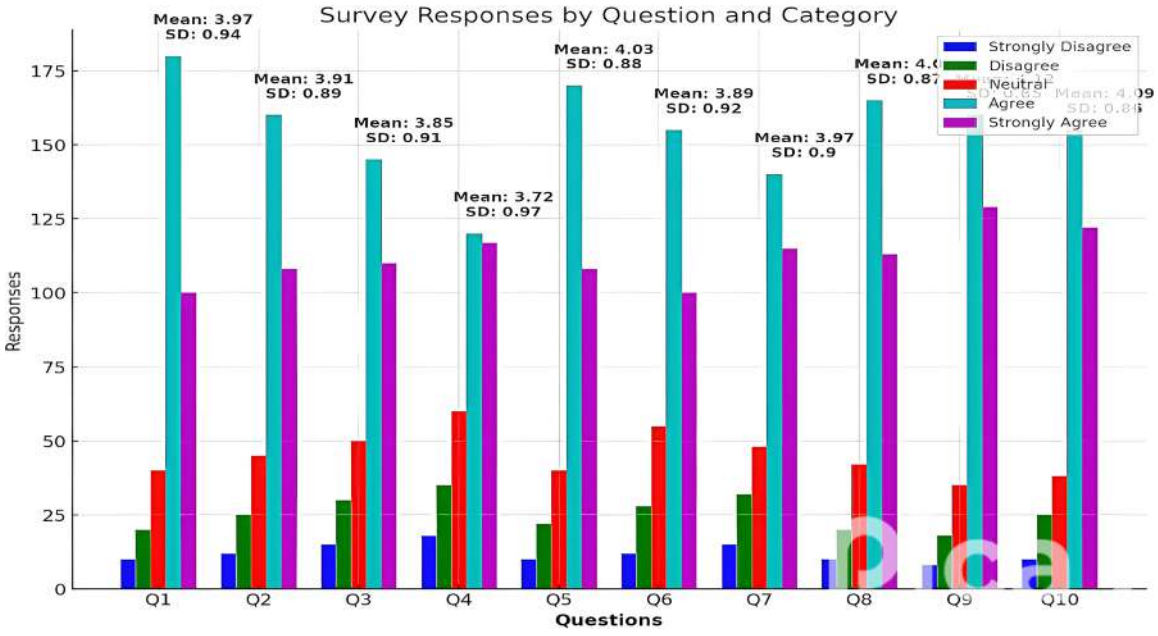

Figure 4. Survey responses.

Table 4. Correlation analysis.

Variable	1	2	3	4	5	6	7	8
1. Data-Driven Decisions	1							
2. Organizational Tasks	0.82	1						
3. Communication	0.75	0.72	1					
4. Transparency and Accountability	0.68	0.65	0.70	1				
5. Educational Trends	0.76	0.71	0.78	0.62	1			
6. Collaboration	0.70	0.68	0.74	0.58	0.68	1		
7. Innovation	0.68	0.64	0.71	0.55	0.67	0.63	1	
8. Leadership Growth	0.73	0.69	0.76	0.60	0.72	0.66	0.68	1

Educational Trends ($r = 0.72$) show significant correlations with Leadership Growth, suggesting that focusing on data-driven strategies, effective communication, and adapting to educational trends can strongly influence leadership development in educational contexts. These correlations underscore the importance of these factors in fostering effective leadership and organizational success within educational institutions.

Table 5. Regression analysis.

Variable	Coefficient (β)	Standard error (SE)	t-value	*p*-value
Intercept	0.50	0.08	6.25	< 0.001
Data-Driven Decisions	0.82	0.06	13.67	< 0.001
Organizational Tasks	0.69	0.07	9.86	< 0.001
Communication	0.76	0.05	15.20	< 0.001
Transparency and Accountability	0.60	0.08	7.50	< 0.001
Educational Trends	0.72	0.06	12.00	< 0.001
Collaboration	0.66	0.07	9.43	< 0.001
Innovation	0.68	0.06	11.33	< 0.001

The regression analysis (Table 5) highlights significant relationships between technology use and leadership growth in educational contexts. Key findings include a strong positive association between Data-Driven Decisions ($\beta = 0.82$, $t = 13.67$, $p < 0.001$), Communication ($\beta = 0.76$, $t = 15.20$, $p < 0.001$) and Educational Trends ($\beta = 0.72$, $t = 12.00$, $p < 0.001$) with Leadership Growth. Organizational Tasks ($\beta = 0.69$, $t = 9.86$, $p < 0.001$), Transparency and Accountability ($\beta = 0.60$, $t = 7.50$, $p < 0.001$), Collaboration ($\beta = 0.66$, $t = 9.43$, $p < 0.001$) and Innovation ($\beta = 0.68$, $t = 11.33$, $p < 0.001$) also show substantial positive correlations. These findings underscore the critical roles of data-driven strategies, effective communication, adaptation to educational trends, and innovative practices in fostering leadership effectiveness within educational institutions.

Research question 3. What challenges leaders face when integrating technology into their leadership roles

Infrastructure and resources

Educational leaders emphasized the critical role of infrastructure and resources in facilitating effective technology integration within educational settings. They highlighted challenges such as outdated technology infrastructure, insufficient funding for upgrades, and limited access to essential hardware and software. These factors pose significant barriers to implementing modern educational practices and leveraging technology to its full potential. An interviewee articulated the frustration, stating,

> *"Our school struggles with outdated equipment and a lack of funding for technology upgrades. This hampers our efforts to integrate new technologies into our classrooms effectively." This quotation underscores the practical challenges educational leaders face in enhancing technological capabilities within their institutions, highlighting the urgent need for investment and support in upgrading infrastructure to support educational innovation.*

Resistance to change

Thematic analysis illuminated various challenges educational leaders face in adopting and implementing educational technologies. Leaders acknowledged resistance from faculty members who are hesitant to embrace new technologies due to concerns about technical proficiency and pedagogical impact. They also cited inadequate training and support as barriers that hinder effective technology integration. Leaders stressed the importance of addressing these challenges through professional development programs, institutional support, and fostering a culture of innovation and collaboration among faculty and staff.

> *"While technology offers immense potential, there are hurdles. Some faculty members are hesitant to embrace new tools, and we struggle with ensuring everyone receives adequate training. It's a process of continuous improvement and support."*

Professional development needs

Leaders emphasized the critical need for ongoing professional development tailored to technology integration. Challenges include providing relevant training opportunities that address diverse learning needs and schedules. Leaders noted the importance of empowering staff with the skills and confidence to effectively utilize technology in educational settings. An interviewee shared,

> *"Continuous professional development is crucial for our teachers to integrate technology effectively. We need to invest more in training that meets their specific needs and challenges."*

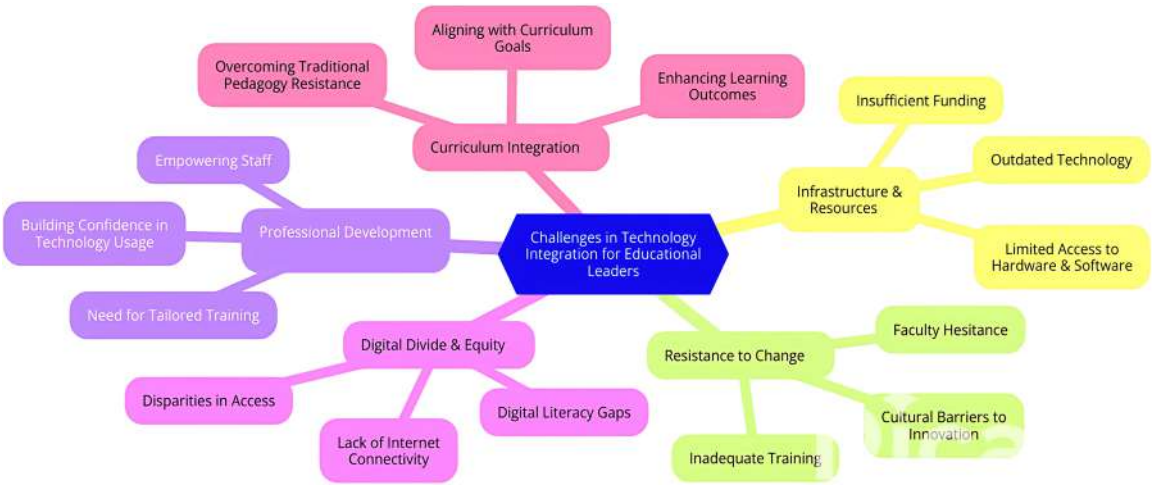

Figure 5. Thematic analysis challenges.

Digital divide and equity

Addressing equity concerns emerged as a significant challenge in technology integration. Leaders expressed concerns about disparities in access to technology among students and faculty, particularly for those from economically disadvantaged backgrounds. Issues such as lack of reliable internet access and digital literacy gaps were highlighted as barriers to equitable learning opportunities. A leader highlighted,

> *"Ensuring all students have equal access to technology is a challenge. Some students struggle with internet access at home, which affects their ability to fully participate in digital learning."*

Integration into curriculum and pedagogy

Leaders stressed the importance of aligning technology integration with curriculum goals and pedagogical practices. Challenges include integrating technology meaningfully into existing curricula, ensuring it enhances learning outcomes, and overcoming resistance from traditional teaching methods. Leaders emphasized the need for strategic planning to integrate technology in ways that support and enhance educational objectives. One leader emphasized,

> *"Integrating technology shouldn't just be about using gadgets. It should complement our curriculum and teaching methods to truly benefit our students' learning."*

The thematic analysis identifies key challenges in technology integration, including outdated infrastructure, resistance to change, and the digital divide. Addressing these requires strategic investments in infrastructure, professional development, and equitable access to technology. Leaders emphasize aligning technology with curriculum goals, fostering innovation, and empowering educators through tailored training to enhance teaching and learning outcomes, as shown in Figure 5.

Discussion

This study explored the role of technology in enhancing leadership effectiveness within higher education institutions in Saudi Arabia, specifically focusing on institutions in Jeddah. The findings highlight the significant impact of technology on various aspects of leadership effectiveness while also identifying key challenges faced by educational leaders in integrating technology. The data collected from surveys and interviews underscore the multifaceted benefits of technology in educational leadership. Educational leaders reported that technology facilitates data-driven decision-making, improves organizational tasks, and enhances communication. These findings align with previous research indicating that technology can significantly streamline administrative processes, thereby allowing leaders to focus on strategic initiatives (Alshahrani & Ally, 2021; Khan & Qureshi, 2021). For example, the ability to analyze educational

data more efficiently allows leaders to make informed decisions that can positively impact student outcomes and institutional performance. Leaders also noted that technology enhances communication among faculty, staff, and students, fostering a more collaborative and transparent educational environment. The positive correlations between technology use and leadership effectiveness (ranging from 0.60 to 0.82) highlight the transformative potential of technology in educational leadership.

Despite the evident benefits, the study also revealed several challenges that hinder effective technology integration. The primary issues include outdated infrastructure, inadequate funding, resistance to change among staff, and the digital divide. These challenges are consistent with findings from other studies that have explored barriers to technology integration in educational settings (Alqahtani, 2022; Alturise & Bashatah, 2022). Educational leaders expressed frustration over these barriers, emphasizing the need for strategic investment and supportive policies to overcome them. One leader highlighted, 'Our school struggles with outdated equipment and a lack of funding for technology upgrades. This hampers our efforts to integrate new technologies into our classrooms effectively'. Such statements underscore the critical need for adequate resources and infrastructure to support technology integration.

The thematic analysis of interviews with educational leaders revealed five key themes, which provide deeper understandings into the challenges and opportunities associated with technology integration. Leaders highlighted the critical need for modern infrastructure and sufficient resources. The lack of updated equipment and reliable internet access significantly impedes technology integration efforts. These issues are echoed in the literature, where inadequate infrastructure is frequently cited as a major barrier (Alqahtani, 2022). There is notable resistance to adopting new technologies among staff and faculty, often stemming from fear of technology, concerns about job security, and a preference for traditional teaching methods. As one leader remarked, 'Some teachers are hesitant to embrace technology in their teaching. They worry about their ability to adapt and prefer sticking to familiar methods'. This resistance is a common issue in educational institutions globally (Alturise & Bashatah, 2022). Continuous professional development is essential for effective technology integration. Leaders emphasized the need for tailored training programs that address the specific challenges and needs of educators. This finding aligns with previous research that highlights the importance of professional development in fostering technology adoption (Khan & Qureshi, 2021). Ensuring equitable access to technology is a significant concern. Disparities in access to digital devices and internet connectivity affect both students and educators, exacerbating existing inequalities. Leaders stressed the importance of policies aimed at bridging the digital divide to ensure all stakeholders benefit from technological advancements (Alshahrani & Ally, 2021). Aligning technology with curriculum goals and pedagogical practices is crucial. Leaders stressed the importance of strategic planning to integrate technology in ways that enhance learning outcomes. Effective integration requires a clear understanding of how technology can support and enrich educational practices (Khan & Qureshi, 2021).

Conclusion

The findings of this study highlight the transformative potential of technology in enhancing leadership effectiveness within higher education institutions (HEIs). Grounded in the framework of Transformational Leadership Theory, the study demonstrates how leaders can inspire and motivate their teams to embrace technology, fostering innovation and adaptability within their institutions. For instance, leaders who exhibit transformational behaviors effectively use technology to drive cultural and organizational change, thereby aligning institutional practices with evolving educational demands.

Similarly, the Technology Acceptance Model (TAM) provides valuable insights into the adoption process. The study underscores how leaders' perceptions of technology's usefulness and ease of use significantly influence its integration. By understanding and addressing these perceptions, institutions can develop targeted strategies to enhance technology adoption among their leaders and faculty members.

This research contributes to these theoretical frameworks by illustrating their application in the context of Saudi Arabian HEIs. It provides empirical evidence on how technology enables data-driven decision-making, enhances communication, and improves strategic planning—all essential components of effective leadership. By bridging theoretical insights with practical implications, this study offers a roadmap for leveraging technology to drive leadership excellence in HEIs.

Implications

The findings of this study have several implications for practice. First, there is a clear need for increased investment in technological infrastructure and resources. Educational institutions must prioritize upgrading outdated equipment and ensuring reliable internet access to support technology integration. This is consistent with recommendations from previous research (Alqahtani, 2022). Universities should consider allocating at least 10% of their annual operational budgets specifically toward upgrading digital infrastructure, ensuring high-speed connectivity, and purchasing classroom and administrative technologies. Second, addressing resistance to change requires a multifaceted approach, including providing comprehensive professional development and fostering a culture of innovation. Leaders must create an environment where educators feel supported and encouraged to experiment with new technologies (Alturise & Bashatah, 2022). This can be achieved by offering mandatory technology onboarding and literacy programs for all newly hired faculty and leadership personnel, as well as providing ongoing digital workshops throughout the academic year. Establishing a digital innovation task force within each institution, comprising faculty, IT staff and administrators, can help lead these efforts and promote a shared vision for digital transformation. Third, policies aimed at bridging the digital divide are essential to ensure all students and educators have equitable access to technology. This includes providing sufficient devices and internet connectivity, particularly in under-resourced areas (Alshahrani & Ally, 2021). Institutions should collaborate with national initiatives and private-sector partners to distribute subsidized or loaned devices to students and staff, especially in rural or economically disadvantaged regions. Regular technology audits should be implemented to assess gaps in access, usage and performance, ensuring responsive and inclusive policy development.

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M.A.A.: conceptualization and design, methodology, analyzing and interpreting the data, writing the original draft, review and editing, revising critically for intellectual content.

Author contributions

CRediT: **Megren Abdullah Altassan**: Conceptualization, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Data availability statement

The data that supported the findings of this study are available from the corresponding author upon reasonable request.

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Fostering faculty well-being: evidence on human resource practices for a psychologically healthy academia

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Abstract

Purpose – This study aims to examine how strategic human resource practices can help reduce stress among faculty members in higher education institutions (HEIs) by strengthening their internal psychological resources. It explores how different forms of intelligence – technological, emotional and spiritual – shape the effectiveness of these practices, offering a nuanced understanding of how institutions can better support academic staff in demanding and evolving work environments.

Design/methodology/approach – A structured questionnaire was distributed via an online survey to 438 faculty members across multiple HEIs in India, using a non-probability snowball sampling approach. This study used well-established psychometric scales to measure high-performance human resource practices (HPHRPs), psychological capital (PsyCap), artificial intelligence (AI), emotional intelligence, spiritual intelligence and perceived stress. Confirmatory factor analysis was conducted to establish construct validity, and moderated-mediation analyses were performed to test the hypothesized relationships.

Findings – The results indicate that HPHRPs play a meaningful role in alleviating stress by fostering greater psychological resilience among faculty members. PsyCap serves as a key pathway through which these practices exert their influence. Notably, the use of AI tools amplifies the positive effect of human resource practices on psychological resources. This relationship is further strengthened by individuals' emotional awareness and regulation abilities, which enhance the synergy between technology use and supportive work

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practices. Moreover, a sense of spiritual purpose and alignment with institutional values further buffers the impact of stress, reinforcing the role of deeper meaning and connection in sustaining well-being within academic environments.

Originality/value – This study sheds new light on how people-oriented management practices can ease workplace stress when embedded in environments that also nurture technological fluency, emotional awareness and spiritual meaning. Rather than treating these elements in isolation, the findings suggest that reducing stress in academic settings requires a broader view – one that sees human resource systems as deeply interconnected with how individuals experience purpose, connection and adaptability. When faculty feel supported not just by procedures but by values, emotions and enabling tools, they become more resilient and psychologically empowered. In doing so, this study challenges fragmented approaches to stress management and calls for more holistic strategies that recognize the full spectrum of what it means to thrive at work.

Keywords Artificial intelligence, Emotional intelligence, Spiritual intelligence, High-performance HR practices, Psychological capital, Higher educational institutions, India

Paper type Research paper

1. Introduction

Higher education institutions (HEIs) today are at a crossroads. Amid intensifying demands for performance, constant adaptation to digital platforms and growing expectations from students and administrators alike, faculty members are increasingly experiencing psychological strain. Reports of stress, emotional fatigue and burnout are no longer isolated incidents – they reflect deeper tensions between institutional pressures and personal well-being (e.g. Almaiah *et al.*, 2020; D'Souza *et al.*, 2023; Hammoudi Halat *et al.*, 2023; Mosleh *et al.*, 2022; Lim and Teo, 2023). In brief, faculty members now operate in environments that demand not only subject expertise but also emotional resilience, technological adaptability and alignment with institutional values – pressures that traditional academic support systems often fail to address.

In this context, high-performance human resource practices (HPHRPs) have gained prominence. These practices – designed to enhance employees' abilities, motivation and opportunities – aim to align individual capacities with organizational objectives (Chuang *et al.*, 2013; Jones and Wright, 1992). While widely associated with improved job satisfaction and performance outcomes (Jiang *et al.*, 2012; Miao *et al.*, 2016), their potential to alleviate psychological strain in complex academic environments remains underexplored. Existing research tends to emphasize operational effectiveness, leaving important questions about the emotional and existential effects of human resource (HR) design unanswered.

This study addresses this oversight by investigating how HPHRPs contribute to reduced perceived stress through the development of psychological capital (PysCap) – a multidimensional construct encompassing self-efficacy, hope, optimism and resilience (Avey *et al.*, 2010; Luthans *et al.*, 2007). PysCap is increasingly recognized as a foundational psychological resource that enables employees to withstand adversity, adapt to change and maintain well-being. Yet, its formation is not solely dependent on HR practices; it is shaped by contextual conditions that either facilitate or constrain its development.

To account for these contextual dynamics, the study introduces three critical forms of moderating capacity: emotional intelligence (EI), which supports emotional self-regulation and interpersonal effectiveness (Joseph *et al.*, 2015; Mayer and Salovey, 1997); artificial intelligence (AI), which influences how faculty interact with data, systems and administrative processes (Schepman and Rodway, 2022; Upadhyay and Khandelwal, 2018); and spiritual intelligence (SPINT), which enhances employees' sense of meaning, purpose and alignment

with organizational values (Ashmos and Duchon, 2000; Vasconcelos, 2020). Each of these capacities influences the relationship between HR practices, psychological resources and perceived stress in distinct but interconnected ways.

Despite growing interest in each of these elements – HPHRPs, PsyCap, AI, EI and SPINT – prior research has often treated them in isolation (e.g. Alston *et al.*, 2010; Jiang *et al.*, 2012; Hwa and Amin, 2016; Miao *et al.*, 2016; Sy *et al.*, 2006). Little is known about how they interact as part of a systemic approach to stress mitigation in higher education, leading to the following research question:

RQ1. How do high-performance human resource practices reduce perceived stress among HEI faculty through psychological capital, and how is this process shaped by the interacting roles of artificial, emotional, and spiritual intelligence?

To address it, the study surveyed 438 faculty members from HEIs across India and analyzed the data using moderated mediation techniques via PROCESS macro. The results confirmed that HPHRPs reduce perceived stress by enhancing PsyCap, which plays a critical mediating role. Crucially, the effects of HPHRPs on PsyCap are significantly amplified when faculty members actively engage with AI – especially those with high EI – demonstrating a powerful synergy between technological adaptability and emotional competence. SPINT further strengthens the stress-buffering role of PsyCap by anchoring employees in meaning and value alignment. These findings break new ground by showing that the effectiveness of HPHRPs is contingent not only on organizational design but also on how individuals harness digital, emotional and spiritual capacities. The study offers a paradigm shift: managing stress in academic settings requires an integrated approach that embeds AI readiness, emotional skills and existential purpose into human resource strategy.

The remainder of this paper organized as follows: In Section 2, we provide theoretical underpinnings and hypotheses development. In Section 3, we explain the methodology, and in Section 4, we explain the analysis. Section 5 is devoted to the discussion that includes the main findings, theoretical contributions, practical implications, limitations, suggestions for future research and conclusion.

2. Theoretical premises

This study draws on two complementary theoretical foundations: the ability–motivation–opportunity (AMO) framework (Appelbaum *et al.*, 2000) and conservation of resources (COR) theory (Hobfoll, 1989). Widely adopted in human resource management (HRM) research (Bos-Nehles *et al.*, 2023; Kim *et al.*, 2015), AMO theory provides a foundational lens for understanding how HPHRPs enhance employee effectiveness. According to this framework, organizational performance depends on three interlocking elements: employees' abilities (i.e. the psychological, cognitive and technical competencies to perform tasks effectively; Blumberg and Pringle, 1982; Marin-Garcia and Martinez Tomas, 2016), motivation (the desire and willingness to act; Bos-Nehles *et al.*, 2023; van Iddekinge *et al.*, 2018) and opportunity (external conditions that enable or constrain action; Blumberg and Pringle, 1982).

HPHRPs embody this triad through targeted practices that build skills, inspire effort and remove structural barriers to performance (Gardner *et al.*, 2011; Jiang *et al.*, 2012; Chuang *et al.*, 2013). When well-executed, these practices create work environments where faculty members are equipped, empowered and enabled to succeed (Kehoe and Wright, 2013). In the context of HEIs, such alignment is essential for attracting, developing and retaining talent capable of navigating complex academic demands. Building on prior evidence (Pham *et al.*, 2018), we propose that HPHRPs foster PsyCap

by reinforcing employees' confidence (ability), engagement (motivation) and behavioral agency (opportunity). Recent systematic reviews have affirmed the explanatory power of the AMO framework in linking HR practices to positive organizational outcomes (Kaur and Malik, 2025), further supporting its relevance to our study.

The second theoretical pillar is COR theory (Hobfoll, 1989; Hobfoll *et al.*, 2018), which emphasizes that individuals strive to acquire, protect and accumulate valued resources – tangible and intangible – to cope with stress and maintain performance. In academic settings, these resources range from personal attributes (e.g. self-efficacy and optimism) to material and social assets (e.g. technology access and collegial support). PsyCap, in this framework, represents a dynamic psychological resource that faculty members develop to adapt effectively to adversity, particularly in high-stress environments such as those shaped by the COVID-19 pandemic (Antony *et al.*, 2023; Siluvai *et al.*, 2023).

Consistent with Hobfoll's, (1989, p. 317) assertion that individuals "acquire resources to position themselves so that they are less vulnerable to future resource loss," faculty members proactively cultivate reservoirs of psychological resilience, often through professional development (e.g. learning new digital tools) or social investment. This resource-building process enhances their capacity to meet unpredictable demands. COR theory has been widely used to explain stress-related phenomena including burnout, work–family conflict and organizational citizenship behavior (Eldor and Harpaz, 2016; Halbesleben, 2006), making it especially well-suited to theorize the stress-mitigating role of PsyCap.

Together, AMO and COR offer a robust theoretical scaffold for understanding how HPHRPs reduce perceived stress by fostering PsyCap, and how this mediating process is conditioned by faculty members' technological, emotional and SPINTs. The hypothesized relationships are visually summarized in the conceptual model (Figure 1).

While AMO theory explains how HR practices enhance individual capabilities, motivation and opportunities for performance, it does not explicitly address how individuals respond to environmental demands that threaten well-being or psychological stability. This is where COR theory becomes essential. COR complements AMO by providing a stress-oriented lens, emphasizing how individuals deploy and protect psychological resources – such as PsyCap – when facing adverse conditions. By combining AMO and COR, our

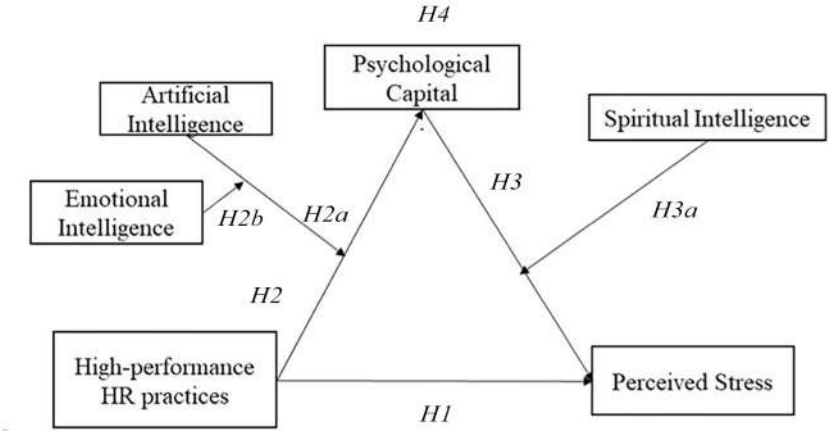

Figure 1. Conceptual model
Source: Authors' own elaboration

framework captures both the resource-enabling function of HR practices and the resource-conserving behavior of individuals under pressure. This theoretical integration allows us to model PsyCap not merely as a byproduct of HR systems but as a strategic mediating resource that links structural HR inputs to psychological outcomes. In doing so, we extend both theories: AMO by incorporating stress-related dynamics, and COR by embedding resource accumulation into systemic HR processes. This integrative lens also underpins the model's novelty – showing that the success of HR practices in reducing stress hinges on the alignment between organizational interventions and individual resource ecologies (Kiazad *et al.*, 2015).

2.1 Hypotheses development

Faculty members in various countries faced stress at work, particularly during the post-pandemic period, in Nigeria (Adekunle and Agboola, 2022), Malaysia (Ahmad and Hussain, 2023), Saudi Arabia (Al-Harbi, 2022), Jordan (Alqudah and Mohammed, 2022), Palestine (Al-Shobaki *et al.*, 2023), South Africa (Czerniewicz and Brown, 2022) and Singapore (Lim and Teo, 2023). When HR managers implement high-performing activities, employees are more likely to use their abilities, skills and competence to reduce perceived stress generated by work and the environment (Batta *et al.*, 2023; Boulet and Dextras-Gauthier, 2025; Iram *et al.*, 2024). A growing body of evidence suggests that HPHRPs can help alleviate perceived stress when implemented thoughtfully. For instance, Topcic *et al.* (2015) found that HPHRPs designed to increase job resources – such as participative decision-making and flexible working arrangements – can reduce employees' perceived stress, though practices framed as performance demands may increase it. Similarly, Jyoti *et al.* (2015), in their study of teachers in professional colleges, reported that bundled HPHRPs reduced emotional exhaustion, a key correlate of perceived stress. Sheehan and Garavan (2021) further demonstrated that supportive HR practices in HEIs were associated with lower levels of burnout and stress among faculty members. Collectively, these studies suggest that when HPHRPs are configured to emphasize employee development, empowerment and support, they can act as organizational resources that mitigate the stressors inherent in academic roles. Accordingly, we offer the following hypothesis:

H1. HPHRPs have a significant and negative influence on perceived stress.

Faculty members' PsyCap – comprising hope, self-efficacy, resilience and optimism – can be significantly enhanced when organizational HR practices are designed to empower, motivate and engage. HPHRPs, by promoting rigorous selection, targeted training and inclusive performance systems, serve as key organizational levers to develop such psychological strengths. This is supported by multiple empirical studies. For example, Miao *et al.* (2021) found a positive relationship between HPHRPs and PsyCap among employees in 44 Chinese firms. Similarly, Vuong (2022), surveying frontline bank employees in Vietnam, and Yıldırım *et al.* (2025), in a study of Turkish academics, both reported that employees exposed to high-performance HR systems developed stronger PsyCap. These findings reinforce the theoretical view that AMO-enhancing HR systems promote not only job performance but also internal psychological capacities (Luthans and Youssef-Morgan, 2017). In the context of HEIs, faculty members are particularly likely to build PsyCap when they are included in participatory training, collaborative work design and feedback-rich environments. Such interventions enhance their confidence, goal persistence and coping resources – essential for navigating the emotional demands of academic work:

H2. HPHRPs have a significant and positive influence on PsyCap.

Several studies in the past have empirically found that PsyCap is a guaranteed resource for employees to cope with stress (Abbas and Raja, 2015; Avey *et al.*, 2010; Li *et al.*, 2015). In a recent study conducted on 388 faculty members in India, researchers reported a negative relationship between PsyCap and stress (Bidi *et al.*, 2024). In another survey of 385 faculty members in Turkey, researchers found that PsyCap has lessened job stress (Toprak *et al.*, 2022). During the global pandemic, the researchers found that the four dimensions of PsyCap (hope, efficacy, resilience and optimism) were a practical resource for employees to cope with stress (Maykrantz *et al.*, 2021). In India, a recent study of 507 public sector employees revealed that PsyCap was beneficial in managing stress experienced during the pandemic (Pradhan *et al.*, 2024). Thus, we advance the following hypothesis based on abundant evidence and logos:

H3. PsyCap has a significant and negative influence on perceived stress.

While the direct effects of HPHRPs on perceived stress are understandable (as explained in *H1*), it is also possible that the direct effect may be lessened through PsyCap. By implementing HPHRPs, AMO dimensions help employees expand their PsyCap, which will alleviate perceived stress (Bello-Pintado, 2015; Boxall, 2012). In this study, we speculate a decisive mediating role of PsyCap in reducing the negative effect of HPHRPs on perceived stress. PsyCap as a mediator between organizational variables has been well documented in literature (Goswami and Agrawal, 2023; Shah *et al.*, 2023; Zhao *et al.*, 2025). For example, Vasudevan and Suganthi (2023) investigated the mediating role of PsyCap in the relationship between new working methods and life satisfaction. Working on similar lines, we propose to study the mediation of PsyCap between HPHRPs and perceived stress and state the hypothesis as follows:

H4. PsyCap mediates the relationship between HPHRPs and perceived stress.

With digital transformation, HEIs are switching their tuition practices by implementing the latest tools available for pedagogical purposes (Komljenovic, 2022; McGrath *et al.*, 2023), and several researchers documented the application of AI by faculty members in HEIs (Bearman *et al.*, 2022; Carvalho *et al.*, 2022; Luckin *et al.*, 2022). Mendy (2020) observed that HR development managers need to identify workplace stress and then design initiatives for such stress, and in this process, PsyCap plays a vital role (Luthans *et al.*, 2007). There is consensus among scholars that AI offers a personalized learning environment whereby faculty members can see each student's needs and provide helpful feedback (Abuhassna, 2024; Rahimi and Sevilla-Pavón, 2024). With the help of AI, faculty members can analyze student data and predict student success (Cerratto Pargman and McGrath, 2021) and incorporate AI tools for assessing student performance by automatic grading systems in managing large classes (Burrows *et al.*, 2015). Extant research reported that when faculty members who have high knowledge and proficiency in AI are successful in designing their course activities and engage in effective pedagogical techniques (Galindo-Domínguez *et al.*, 2023; Wang *et al.*, 2023).

While the direct effects of AI are understandable, this study argues that AI plays a moderating role by strengthening the positive relationship between HPHRPs and perceived stress mediated through PsyCap. The underlying logic for this proposition is that faculty members can divert their energies by adopting AI tools in pedagogical instructions and assessing students' performance. To our knowledge, no prior studies investigated such a moderating effect.

In addition, EI plays a vital role in achieving superior performance by understanding self and others emotions and managing the emotions in the workplace (Joseph *et al.*, 2015; Mayer *et al.*, 2008; Mayer and Salovey, 1997; Pekaar *et al.*, 2017), it will be interesting to see how EI interacts with AI to alleviate the perceived stress stemming from work. More precisely, when faculty members encounter stress due to implementing technological innovations with limited facilities, conflicts are more likely to erupt. How individuals manage these emotions plays a vital role in reducing, if not mitigating, the stress associated with performing tasks.

This research explores the three-way interaction between HPHRPs, AI and EI in enhancing PsyCap. Since none of the prior studies focused on this double moderation, we offer the following exploratory hypotheses:

H2a. AI positively moderates between HPHRPs and PsyCap such that at higher (lower) levels of AI, HPHRPs result in higher (lower) levels of PsyCap.

H2b. EI (second moderator) and AI (first moderator) influence the relationship between HPHRPs and perceived stress mediated through PsyCap.At higher (lower) levels of EI, higher (lower) AI interacts with HPHRPs to result in higher (lower) levels of PsyCap.

Several organizations have emphasized SPINT and workplace spirituality in maintaining smooth relationships and effective functioning (Nayyar *et al.*, 2024). For example, in HEIs in India, one study on 810 students found that SPINT is instrumental in developing leadership qualities (Prabhu and Mehta, 2023). In Indian organizations, some scholars found that workplace spirituality, which depends on SPINT, is significantly negatively related to stress (Saxena *et al.*, 2020). A study conducted on 473 respondents in India by Saini and Seema (2020) found that SPINT significantly negatively affects stress. In a recent study conducted on 381 respondents from universities in India, researchers found that SPINT reduced depression symptoms significantly (Rajan *et al.*, 2024). Expecting the positive effect of SPINT, we attempt to explore the moderating effect of SPINT in strengthening the negative relationship between HPHRPs and perceived stress. In other words, when people exhibit a high level of SPINT by finding meaning in their work and seeing that their work aligns with organizational goals, it is more likely that they will experience lower levels of stress. To our knowledge, the previous studies have yet to investigate this moderating effect of SPINT. Hence, we offer the following exploratory moderator hypothesis:

H3a. SPINT moderates the relationship between psychological capital and perceived stress such that at higher (lower) levels of SPINT, PsyCap results in lower (higher) levels of perceived stress.

3. Method

3.1 Sampling strategy

This study explores the effect of HPHRPs on perceived stress, mediated by PsyCap and moderated by AI, EI and SPINT. The context of the study is faculty members in HEIs in India – an occupational group experiencing increased stress due to pedagogical shifts and institutional demands post-COVID-19 (Pant and Srivastava, 2019; Pandit and Agrawal, 2022).

We used a structured questionnaire administered via Google Forms, consistent with current best practices in post-pandemic behavioral research (Antony *et al.*, 2023; Jayaraman *et al.*, 2023; Shaik *et al.*, 2023). Though pandemic restrictions had eased, online data

collection remains preferred for its reach and efficiency in targeting busy professionals (Newman *et al.*, 2014). Informed consent was obtained prior to participation.

Given the absence of an accessible sampling frame and the difficulty of accessing this population, we used a combination of convenience, non-probability and snowball sampling. Faculty known to the researchers were initially contacted and asked to share the survey with peers. Participants were assured anonymity and confidentiality. A total of 600 emails were sent.

We obtained informed consent from the respondents before participating in this study. We used convenience, non-probability and snowball sampling, though researchers do not prefer this data collection method. We first contacted known faculty members and procured their friends' emails, who were willing to participate in the survey. We assured the respondents that the data's anonymity and privacy would be protected. Through snowball sampling, we have sent 600 emails to the faculty members working in different parts of the country. We received 438 (73% response rate), and all the surveys were complete. Google Forms only allows a respondent to proceed further after responding to questions. Of the total number (438) faculty members, 210 (47.95%) are from Andhra Pradesh, 141 (32.19%) are from Telangana, 35 (7.99%) are from Tamil Nadu, 24 (5.48%) are from Karnataka, 10 (2.28%) are from Maharashtra, 12 (2.74%) are from Uttar Pradesh and 6 (1.37%) are from Rajasthan. We performed a nonresponse bias check by comparing the first 75 respondents with the last 75 respondents. We found no statistical differences between these two groups regarding all the study variables (Armstrong and Overton, 1977). The demographic profile of respondents is detailed in Table 1.

3.2 Higher education in India: the study context

Education is a powerful growth engine in any country, and India is no exception. A report by the Ministry of Education (2023), India reveals that the HEIs consist of over

Table 1. Demographic profile of respondents

Category	Profile	Total number	%
Gender	Male	255	58.2
	Female	183	41.8
Age (in years)	20–29 years	101	23.1
	30–39 years	157	35.8
	40–49 Years	100	22.8
	50–59 years	80	18.3
Educational qualification	Graduates [B. Tech degrees]	39	8.9
	Masters degrees and Ph. Ds	225	51.4
	Professional degrees [law, accountancy]	174	39.7
Annual income (INR / US $)	Less than Rs. 500,000 ($6,250)	193	44.1
	Rs. 500,000–900,000 ($6,250–$11,250)	102	23.3
	Rs. 900,000–1,400,000 ($11,250– $17,500)	96	21.9
	Rs. 1,400,000–1,900,000 ($17, 750–$23,750)	41	9.4
	Rs. 1,900,000–2,400,000 ($23,750–$30,000)	6	1.4
Employee designation	Assistant professor	261	59.6
	Associate professor	111	25.3
	Professor	66	15.1
Work experience	0–4 years	192	43.8
	5–9 years	73	16.7
	10–14 years	98	22.4
	Above 15 years	75	17.1

Source(s): Authors' own elaboration

1,000 universities (central universities, state universities, private universities, deemed universities and institutes of national importance such as IITs and NITs) and over 42,000 constituent colleges. HEIs are knowledge hubs. The faculty members play a vital role in disseminating knowledge, and the success of these organizations is heavily dependent on the quality of instructors. The administrators in HEIs use recruitment strategies to attract and retain competent faculty to remain competitive in a highly competitive environment. Furthermore, following the global pandemic, increasing competition for competent faculty who are flexible in a changing academic environment where pedagogical tools and instruments have undergone radical change necessitates HPHRPs in HEIs. In addition, the stress imposed by the pandemic has become common among employees in all sectors (Pandit and Agrawal, 2022), including HEIs, calls for a fresh look at HR practices and their impact on perceived stress.

3.3 Measures

We used well-established and tested measures in this study. The indicators for all the constructs were measured on a five-point Likert scale (5 = "strongly agree"; 1 = "strongly disagree").

HPHRPs were measured with three dimensions adapted from Chuang *et al.* (2013). Ability enhancing dimension of HPHRPs was measured with three indicators ($\alpha = 0.78$) and a sample item reads as "In my opinion selection of employees is totally based on their technical skills but not interpersonal skills." Motivation-enhancing dimension HPHRPs was measured with four items ($\alpha = 0.75$) and the sample item reads as: "In my opinion the selection of employees emphasizes their overall fit to the organization (values and personality)."

Opportunity enhancing dimension of HPHRPs was measured with three items ($\alpha = 0.77$), and the sample item reads as: "In my opinion the organization often arranges events for knowledge exchange (e.g. seminar and presentation)." The second-order latent construct HPHRPs has reliability coefficient of 0.81.

PsyCap was measured with seven items ($\alpha = 0.74$) adapted from Luthans *et al.* (2007) and the sample item reads as: "I feel confident in analyzing a long-term problem to find a solution."

EI was measured with four dimensions (self-emotion appraisal [SEA], others' emotional appraisal [OEA], use of emotions [UOE] and regulation of emotions [ROE]) adapted from Salovey and Mayer (1990). SEA dimension was measured with three indicators ($\alpha = 0.76$) and sample item reads as "I have good understanding of my own emotions."

OEA dimension was measured with three indicators ($\alpha = 0.79$) and sample item reads as "I am a good observer of others' emotions."

UOE dimension was measured with three indicators ($\alpha = 0.81$) and sample item reads as "I always tell myself I am a competent person."

ROE dimension was measured with three indicators ($\alpha = 0.76$) and sample item reads as "I am able to control my temper and handle difficulties rationally." The second-order latent variable EI has reliability coefficient of 0.82.

SPINT was measured with three dimensions – meaning at work, conditions for community and alignment with organization value adapted from Ashmos and Duchon (2000). SPINT (meaning at work) was measured with four indicators ($\alpha = 0.81$) and the sample item reads as: "I believe that my spirit is energized by my work." SPINT (conditions for community) was measured with four items ($\alpha = 0.75$), and the sample item reads as "I feel part of a community in my immediate workplace (department and unit)." SPINT (alignment with organization value) was measured with four items ($\alpha = 0.71$), and the sample item reads

as "In my opinion this organization cares about all its employees." The second-order latent construct of SPINT reliability coefficient of 0.78.

AI was measured with eight items (α = 0.76) adapted from Schepman and Rodway (2022), and the sample item reads as "I believe there are beneficial applications of AI."

Perceived stress was measured with nine items (α = 0.83) adapted from Cohen and Williamson (1988), and the sample item reads as "I felt upset because something happened unexpectedly."

3.4 Data analysis strategy

To test our conceptual model, we employed structural equation modeling (SEM) using SPSS. SEM is appropriate for this study given the presence of multiple latent variables and the need to assess both measurement and structural relationships simultaneously. We followed a two-step modeling approach (Anderson and Gerbing, 1988), beginning with a confirmatory factor analysis (CFA) to establish the validity and reliability of the measurement model, followed by estimation of the full structural model.

We assessed internal consistency using Cronbach's alpha and composite reliability (CR), and evaluated convergent and discriminant validity using average variance extracted (AVE) and Fornell–Larcker criterion. Model fit was assessed using indices including the comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA) and Chi-square/df ratio, in line with accepted thresholds (Hair *et al.*, 2014).

We tested mediation via PsyCap using (e.g. bootstrapping methods with 5,000 resamples) and moderation effects of AI, EI and SPINT using interaction terms created through mean-centered variables to minimize multicollinearity (Aiken and West, 1991).

4. Analysis and findings

4.1 Measurement model and confirmatory factor analysis

Before running the structural model, Anderson and Gerbing (1988) suggested the researchers check the measurement model to ensure the reliability and validity of the constructs (Anderson and Gerbing, 1988). Therefore, we first conducted CFA using the LISREL package of covariance-based SEM. Since this study has second-ordered constructs (HPHRPs have three dimensions, EI has four dimensions and SPINT has three dimensions), we presented the results of first-order latent variables in Table 2 and second-order latent constructs in Table 3.

A preliminary look at the table reveals that the factor loadings of all the constructs ranged from 0.71to 0.91, thus over the acceptable levels of 0.70 (Hair *et al.*, 2014). Furthermore, the AVE estimates were well above 0.50, the CR was over 0.50 and the constructs' reliability coefficients were over 0.70. These statistics provide evidence that indicators measure the intended constructs, thus vouching for the reliability and convergent validity of the constructs (Montgomery *et al.*, 2021). The second-order constructs (HPHRPs, EI and SPINT) also have reliability coefficients of over 0.70, AVE values of over 0.50 and CR values of over 0.70, providing evidence of convergent validity.

4.2 Descriptive statistics, convergent validity, discriminant validity and common method bias

The means, standard deviations and zero-order correlations between the variables were captured in Table 4.

The preliminary observation of correlations reveals that the highest correlation was 0.71 ($p < 0.01$) (between EI and SPINT), and the lowest correlation was −0.13 ($p < 0.01$) (between

Table 2. Confirmatory factor analysis

Constructs and the sources of constructs	Alpha	CR	Standardized loadings (λ_{yi})	Reliability (λ^2_{yi})	Variance [var(ε_{yi})]	Average variance extracted estimate $\Sigma(\lambda^2_{yi})/[(\lambda^2_{yi}) + (\text{var}(\varepsilon_i))]$
HPHRP [ability-enhancing dimension] (Chuang et al., 2013)	0.78	0.86				0.60
In my opinion selection of employees is totally based on their technical skills but not interpersonal skills			0.73	0.53	0.47	
I believe that selection of employees emphasizes teamwork ability			0.87	0.76	0.24	
In my opinion organization provides training to improve the interpersonal skills of employees to build good relationships			0.76	0.58	0.42	
In my opinion organization provides training to enhance team-building and teamwork skills of employees			0.74	0.55	0.45	
HPHRP [motivating enhancing dimension] (Chuang et al., 2013)	0.75	0.88				0.64
In my opinion the selection of employees emphasizes their overall fit to the organization (values and personality)			0.75	0.56	0.44	
In my opinion organization provides an extensive orientation program for new employees to learn the history, culture and values of the organization			0.78	0.61	0.39	
I believe the organization rewards employees for sharing new information and knowledge			0.91	0.83	0.17	
I believe employees' bonuses or incentive plans are based primarily on the organizational performance			0.75	0.56	0.44	
HPHRP [opportunity-enhancing dimension] (Chuang et al., 2013)	0.77	0.84				0.63
In my opinion the organization sponsors various social events to encourage contact and relationship building among employees			0.79	0.62	0.38	
In my opinion the organization often arranges events for knowledge exchange (e.g. seminar and presentation)			0.81	0.66	0.34	
In my opinion organization provides team training to facilitate social interaction			0.78	0.61	0.39	
Psychological capital (Luthans et al., 2007)	0.74	0.90				0.57
I feel confident in analyzing a long-term problem to find a solution			0.78	0.61	0.39	
I am confident in my performance that I can work under pressure and challenging circumstances			0.79	0.62	0.38	

(*continued*)

Table 2. Continued

Constructs and the sources of constructs	Alpha	CR	Standardized loadings (λ_{yi})	Reliability (λ^2_{yi})	Variance [var(ε_{yi})]	Average variance extracted estimate $\Sigma(\lambda^2_{yi})/[(\lambda^2_{yi}) + (\text{var}(\varepsilon_i))]$
I feel confident that I can accomplish my work goals			0.71	0.50	0.50	
At work, I always find that every problem has a solution			0.73	0.53	0.47	
If I have to face with bad situation, I believe that everything will change to be better			0.83	0.69	0.31	
I believe that success in the current work will occur in the future			0.72	0.52	0.48	
I usually take stressful things at work in stride			0.70	0.49	0.51	
Emotional intelligence [self emotion appraisal] (Salovey and Mayer, 1990)	0.76	0.81				0.58
I have good understanding of my own emotions			0.74	0.55	0.45	
I really understand what I feel			0.79	0.62	0.38	
I always know whether or not I am happy			0.76	0.58	0.42	
Emotional intelligence [others emotion appraisal] (Salovey and Mayer, 1990)	0.79	0.81				0.59
I am a good observer of others' emotions (OEA)			0.78	0.61	0.39	
I am sensitive to the feelings and emotions of others (OEA)			0.72	0.52	0.48	
I always know my friends' emotions from their behaviour (OEA)			0.80	0.64	0.36	
Emotional Intelligence [use of emotions] (Salovey and Mayer, 1990)	0.81	0.80				0.57
I always tell myself I am a competent person			0.75	0.56	0.44	
I am a self-motivated person			0.73	0.53	0.47	
I would always encourage myself to try my best			0.79	0.62	0.38	
Emotional Intelligence [regulation of emotions] (Salovey and Mayer, 1990)	0.76	0.80				0.57
I am able to control my temper and handle difficulties rationally			0.73	0.53	0.47	
I can always calm down quickly when I am very angry			0.74	0.55	0.45	
I have good control of my own emotions (ROE)			0.79	0.62	0.38	
Spiritual intelligence [meaning at work] (Ashmos and Duchon, 2000)	0.81	0.86				0.60
I experience joy in my work			0.75	0.56	0.44	
I believe others experience joy as a result of my work			0.79	0.62	0.38	
I believe that my spirit is energized by my work			0.83	0.69	0.31	

(*continued*)

Table 2. Continued

Constructs and the sources of constructs	Alpha	CR	Standardized loadings (λ_{yi})	Reliability (λ^2_{yi})	Variance [var(ε_{yi})]	Average variance extracted estimate $\Sigma(\lambda^2_{yi})/[(\lambda^2_{yi}) + (\text{var}(\varepsilon_i))]$
I see a connection between my work and the larger social good for my community			0.73	0.53	0.47	
Spiritual intelligence [conditions for community] (Ashmos and Duchon, 2000)	0.75	0.84				0.57
I feel part of a community in my immediate workplace (department and unit)			0.77	0.59	0.41	
I believe that my supervisor encourages my personal growth			0.72	0.52	0.48	
I feel that when I have fears I am encouraged to discuss them			0.71	0.50	0.50	
I am evaluated fairly here			0.81	0.66	0.34	
Spiritual intelligence [alignment with organization value] (Ashmos and Duchon, 2000)	0.71	0.85				0.59
In my opinion this organization cares about all its employees			0.72	0.52	0.48	
I feel that this organization is concerned about the poor in our community			0.77	0.59	0.41	
I feel positive about the values of the organization			0.80	0.64	0.36	
I feel connected with this organization's goals			0.78	0.61	0.39	
Artificial intelligence (Schepman and Rodway, 2022)	0.76	0.92				0.58
I believe there are beneficial applications of artificial intelligence			0.71	0.50	0.50	
I believe artificial intelligence can have positive impacts on people's well-being			0.79	0.62	0.38	
I believe artificial intelligence is exciting			0.74	0.55	0.45	
I believe artificial intelligent systems can perform better than humans			0.83	0.69	0.31	
I am interested in using artificial intelligent systems in my daily life			0.80	0.64	0.36	
I would like to use artificial intelligent systems in my own job			0.73	0.53	0.47	
I believe artificial intelligent systems can help people feel happier			0.75	0.56	0.44	
I love everything about AI			0.74	0.55	0.45	
Perceived stress (Cohen and Williamson, 1988)	0.83	0.94				0.63
I felt upset because of something happened unexpectedly			0.76	0.58	0.42	
I felt that I am unable to control important things in your life			0.79	0.62	0.38	
I felt nervous and stressed			0.72	0.52	0.48	

(*continued*)

Table 2. Continued

Constructs and the sources of constructs	Alpha	CR	Standardized loadings (λ_{yi})	Reliabili y (λ^2_{yi})	Variance [var(ε_{yi})]	Average variance extracted estimate $\Sigma (\lambda^2_{yi}) / [(\lambda^2_{yi}) + (var(\varepsilon_i))]$
I found that I could not cope with all the things that I had to do			0.82	0.67	0.33	
I felt angry because of things that were outside of my control			0.81	0.66	0.34	
I did not feel confident about my ability to handle my personal problems			0.79	0.62	0.38	
I did not feel that things were going my way			0.85	0.72	0.28	
I could not control irritations in my life			0.75	0.56	0.44	
I did not feel that I was on top of things			0.86	0.74	0.26	

Source(s): Authors' own elaboration

Table 3. Second-order latent variables

Constructs and the sources of constructs	Alpha	Standardized loadings (λ_{yi})	Reliability ($\lambda^2{}_{yi}$)	Variance [var(ε_i)]	Average variance-extracted estimate $\Sigma (\lambda^2{}_{yi})/ [(\lambda^2{}_{yi}) + (var(\varepsilon_i))]$
HPHRP CR = 0.83	0.81				0.63
HPHRP – Ability enhancing		0.74	0.55	0.45	
HPHRP – Motivating enhancing		0.83	0.69	0.31	
HPHRP – Opportunity enhancing		0.80	0.64	0.36	
Emotional intelligence CR = 0.84	0.82				0.56
Self-emotion appraisal (SEA)		0.83	0.69	0.31	
Others-emotion appraisal (OEA)		0.72	0.52	0.48	
Use of emotion (UOE)		0.70	0.49	0.51	
Regulation of emotion (ROE)		0.75	0.56	0.44	
Spiritual intelligence CR = 0.79	0.78				0.56
Spiritual intelligence [meaning at work]		0.74	0.55	0.45	
Spiritual intelligence [conditions for community]		0.79	0.62	0.38	
Spiritual intelligence [alignment with organization value]		0.72	0.52	0.48	

Source(s): Authors ‘own elaboration

Table 4. Correlations, reliability and validity

Variable	Mean	SD	1	2	3	4	5	6	Cronbach's alpha	Composite reliability	Average variance extracted
1. HPHRP	3.67	0.80	*0.79*						0.81	0.83	0.63
2. PsyCap	3.82	0.72	0.50**	*0.75*					0.74	0.90	0.57
3. AI	3.67	0.79	0.41**	0.40**	*0.76*				0.76	0.92	0.58
4. EI	3.86	0.59	0.45**	0.73**	0.36**	*0.75*			0.82	0.84	0.56
5. SPINT	3.72	0.59	0.58**	0.67**	0.44**	0.71**	*0.75*		0.78	0.79	0.56
6. Perceived stress	3.01	0.63	−0.13**	−0.12*	−0.16**	−0.28**	−0.55**	*0.79*	0.83	0.94	0.63

Note(s): **$p < 0.01$; HPHRP = high-performance HRM practices; PsyCap = psychological capital; AI = artificial intelligence; EI = emotional intelligence; SPINT = spiritual intelligence; Elements in diagonal and italic are the square root of average variance extracted (AVE)
Source(s): Authors' own elaboration

HPHRPs and perceived stress. Furthermore, the square root of AVEs between PsyCap and AI were 0.76 and 0.75, respectively and are greater than the correlations between PsyCap and AI (r = 0.40; p < 0.40). Similarly, the correlation between SP and perceived stress (r = −0.55; p < 0.01) was less than the square root of AVEs of 0.75 and 0.79 for SP and perceived stress, respectively. These statistics suggest that the data was not infected with multicollinearity (Tsui *et al.*, 1995). To assess the variance inflation factor (VIF) values for all the constructs, we found that these were less than 5, suggesting that the data did not have any problem of multicollinearity (Montgomery *et al.*, 2021).

Convergent validity is assessed by examining the AVE values of the indicators. As shown in Tables 2 and 3, the AVE values of each construct were well above 0.5, and convergent validity and internal consistency of the indicators were established (Hair *et al.*, 2014). Discriminant validity is confirmed when the square root of the AVE values of the variables is greater than the correlation between the variables (Henseler *et al.*, 2015). These statistics, CFA values and reliability coefficients (Cronbach's alpha and CR) confirm the discriminant validity of the six variables in this research.

This research is quantitative and survey based as we collected data on exogenous and endogenous variables from the respondents, and hence, common method bias (CMB) needs to be checked (Kraus *et al.*, 2020; Podsakoff and Organ, 1986). We tested CMB with several techniques. First, to minimize CMB, we randomized the survey questions as suggested by Podsakoff *et al.* (2012). Second, we did a traditional Harman's single factor test and found that a single factor accounted for 24.62% (50%) variance, suggesting that CMB is not a problem in this research (Podsakoff *et al.*, 2003). Second, we compared the 13 first-order factor model with 12 alternative measurement models (see Table 5) and found that the 13-factor model was the best fit of the data [χ^2 = 2548.42; df = 972; χ^2/df = 2.62; RMSEA = 0.052; root mean-square error (RMR) = 0.041; standardized RMR = 0.049; CFI = 0.93; non-normal fit index (NNFI) = 0.91; goodness of fit index (GFI) = 0.89]. In general, when RMSEA values are less than 0.08 and CFI values are over 0.90, it vouches for a good fit of the data to the model. On the contrary, the single-factor yielded poor fit [χ^2 = 3994.62; df = 1041; χ^2/df = 3.84; RMSEA = 0.094; RMR = 0.088; standardized RMR = 0.82; CFI = 0.60; GFI = 0.65]. As a third check, we performed a latent variable check recommended by Kock (2015) and loaded all the indicators into one factor each time and found that the inner VIF values of all the constructs were less than 3.3, indicating that the data was not infected by CMB. The summary of measurement properties of various models is presented in Table 5.

4.3 Testing hypothesis1–hypothesis4

To check direct hypotheses (*H1–H3*) and mediation hypothesis (*H4*), we used model number 4 of PROCESS macros (Hayes, 2018). The results are presented in Table 6.

The regression coefficient of HPHRPs on perceived stress was negative and significant (β = −0.26; t = −5,61; p < 0.001). The results based on 20,000 bootstrap samples show that the 95% bias-corrected confidence interval (BCCI) was −0.4491 (LLCI) and −0.0655 (ULCI). The model was significant and explains 15.9% variance in the perceived stress, and the magnitude is medium (f^2 = 0.19), [the effect size f^2 between 0.02 and 0.15 represents "small"; f^2 between 0.15 and 0.35 represent medium effect size and f^2 > 0.35 represents "large effect size" (Cohen, 1988)] and is statistically significant [R^2 = 0.159; F(1,436) = 11.35 p < 0.001]. These results support *H1* that HPHRPs were significant predictors of perceived stress.

The regression coefficient of HPHRPs on PsyCap, as proposed in *H2*, was positive and significant (β = 0.71; t = 17.06; p < 0.001). The 95% (BCCI) LLCI and ULCI were 0.6318 and 0.7963 respectively. The model was significant and explains 40.1% variance in PsyCap

Table 5. Comparison of measurement models

Model	Factors	χ^2	df	χ^2/df	$\Delta\chi^2$	RMSEA	RMR	Standardized RMR	CFI	TLI=NNFI	GFI
Null model		8872.30	1174								
Baseline model	Base line 13 factor model	2548.42	972	2.62		0.052	0.041	0.049	0.93	0.91	0.89
Model 1	12-factor model	2615.76	984	2.66	67.34**	0.059	0.052	0.056	0.92	0.89	0.88
Model 2	11-factor model	2641.31	995	2.65	92.89**	0.065	0.060	0.057	0.89	0.87	0.85
Model 3	10-factor model	2695.82	1005	2.68	147.4**	0.068	0.064	0.059	0.81	0.80	0.79
Model 4	Nine-factor model	2782.16	1014	2.74	233.74**	0.067	0.064	0.058	0.77	0.75	0.74
Model 5	Eight-factor model	2815.54	1022	2.75	267.12**	0.071	0.068	0.062	0.76	0.73	0.70
Model 6	Seven-factor model	3351.47	1029	3.26	803.05**	0.075	0.083	0.074	0.67	0.65	0.71
Model 7	Six-factor model	3462.74	1035	3.35	914.32**	0.076	0.080	0.076	0.66	0.65	0.71
Model 8	Five-factor model	3498.78	1040	3.36	950.36**	0.079	0.085	0.078	0.64	0.63	0.70
Model 9	Four-factor model	3585.51	1044	3.43	1037.09**	0.084	0.086	0.079	0.65	0.63	0.70
Model 10	Three-factor model	3655.47	1047	3.49	1107.05**	0.085	0.084	0.080	0.63	0.61	0.69
Model 11	Two-factor model	3845.29	1049	3.67	1296.87**	0.089	0.085	0.080	0.61	0.60	0.67
Model 12	One-factor model	3994.62	1050	3.80	1446.2**	0.094	0.088	0.082	0.60	0.60	0.65

Note(s): $^{**}p < 0.01$; HPHRPAE = high-performance HRM practices ability enhancing; HPHRPME = high-performance HRM practices motivation enhancing; HPHRPOE = high-performance HRM practices opportunity enhancing; PsyCap = psychological capital; EISEA = emotional intelligence self-emotional appraisal; EIOEA = emotional intelligence others-emotion appraisal; EIUOE = emotional intelligence use of emotions; EIROE = emotional intelligence regulation of emotions; SIMW = spiritual intelligence [Meaning at work]; SICC = spiritual intelligence [conditions for community]; SIAOV = spiritual intelligence [alignment with organization value]; AI = artificial intelligence; PSTR = perceived stress 12-factor model: HPHRPAE + HPHRPME; HPHRPOE; PSYCAP; EISEA; EIOEA; EIUOE; EIROE; SIMW; SICC; SIAOV; AI; PSTR 11-factor model: HPHRPAE + HPHRPME + HPHRPOE; PSYCAP; EISEA; EIOEA; EIUOE; EIROE; SIMW; SICC; SIAOV; AI; PSTR 10-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP; EISEA; EIOEA; EIUOE; EIROE; SIMW; SICC; SIAOV; AI; PSTR Nine-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA; EIOEA; EIUOE; EIROE; SIMW; SICC; SIAOV; AI; PSTR; Eight-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA; EIUOE; EIROE; SIMW; SICC; SIAOV; AI; PSTR Seven-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA + EIUOE; EIROE; SIMW; SICC; SIAOV; AI; PSTR; Six-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA + EIUOE + EIROE; SIMW; SICC; SIAOV; AI; PSTR; Five-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA + EIUOE + EIROE + SIMW; SICC; SIAOV; AI; PSTR; Four-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA + EIUOE + EIROE + SIMW+ SICC; SIAOV; AI; PSTR Three-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA + EIUOE + EIROE + SIMW + SICC + SIAOV; AI; PSTR; Two-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA + EIUOE + EIROE + SIMW + SICC + SIAOV + AI; PSTR; One-factor model: HPHRPAE + HPHRPME + HPHRPOE + PSYCAP + EISEA + EIOEA + EIUOE + EIROE + SIMW + SICC + SIAOV + AI + PSTR

Source(s): Authors' own elaboration

Table 6. Testing *H1*, *H2* and *H3*

Hypotheses	Relationship	coeff	se	t	*p*	Boot LLCI	Boot ULCI	R^2 and F values	Result
H1	HPHRP→Perceived stress	−0.2621	0.0467	−5.6124	0.0003	−0.4491	−0.0655	0.159F (1,436) = 11.35	Supported
H2	HPHRP→PsyCap	0.7141	0.0419	17.0615	0.0000	0.6318	0.7963	0.401F (1,436) = 291.09	Supported
H3	PsyCap→Perceived stress	−0.3614	0.1089	−3.3196	0.0010	−0.5754	−0.1474	0.159F (2,435) = 15.62	Supported

Source(s): Authors' own elaboration

because of HPHRPs, and the effect size is large [R^2 = 0.401; $F(1,436)$ = 291.09; $p < 0.001$; f^2 = 78.7], thus supporting *H2*.

H3 proposes that PsyCap is negatively associated with perceived stress. The results reveal that the regression coefficient of PsyCap on perceived stress was negative and significant ($\beta = -0.36$; $t = -3.31$; $p < 0.001$; BCCI LLCI = −0.5754; BCCI ULCI = −0.1474). The model is significant and explains 15.9% of the variance in PsyCap, and the effective size is medium [R^2 = 0.159; $F(2,435)$ = 15.62; $p < 0.001$; f^2 = 21.4]. These results render support for *H3*.

PsyCap as a mediator between HPHRPs and perceived stress (*H4*) was checked by verifying whether the indirect effect was significant (Hayes, 2018). Table 7 shows the mediation results, and Table 8 shows the indirect effect.

The total effect of HPHRPs on perceived stress consisted of a direct effect (−0.1061) and an indirect effect (−0.1560), which comes to −0.2621. Furthermore, the indirect effect (−0.1560) was a product of the effect of HPHRPs on PsyCap (0.4319) and the effect of PsyCap on perceived stress (−0.3614). As can be seen from Table 8, the result based on 20,000 bootstrap samples shows that the indirect effect is significant [Boot LLCI = −0.0419; and Boot ULCI = −0.0384], and since zero was not contained in the confidence intervals, the mediation hypothesis is supported.

4.4 Testing moderation hypotheses H2a, H2b and H3a

We used PROCESS macros to test the two-way interaction (*H2a*), three-way interaction (*H2b*) and two-way interaction (*H3a*) and presented the results in Table 9.

As shown in Table 9, the regression coefficient of the interaction term (HPHRPs × AI) was significant [$\beta_{\text{HPHRP x AI}} = 0.36$; $t = 3.31$; $p < 0.001$; Boot LLCI (0.1474); Boot ULCI (0.5754)]. These results support *H2a*, which shows that AI moderates the relationship between HPHRPs and PsyCap. The visualization of two-way interaction is presented in Figure 2.

Table 7. Results of mediation analysis (HPHRP→PsyCap→perceived stress)

Relationship	Coeff	se	*t*	*p*	Boot LLCI	Boot ULCI
HPHRP→Perceived stress	−0.1061	0.0304	−3.4901	0.0010	−0.3747	−0.0375
HPHRP→PsyCap	0.4319	0.0419	10.3078	0.0000	0.6318	0.7963
PsyCap→Perceived stress	−0.3614	0.1089	−3.3196	0.0010	−0.5754	−0.1474
Total effect of HPHRP→Perceived stress	−0.2621	0.0467	−5.6124	0.0003	−0.4491	−0.0655

Source(s): Authors' own elaboration

Table 8. Indirect effect (*H4*)

Relationship	Effect	se	Boot LLCI	Boot ULCI
HPWP→ PsyCap → Perceived stress	−0.1560	0.0365	−0.0419	−0.0384

Note(s): Total Effect of HPWP → Perceived stress = Direct effect (−0.1061) + Indirect effect (−0.1560) = −0.2621 Indirect effect = (0.4319) (−0.3614) = −0.1560; *n* = 438; Boot LLCI refers to the lower bound bootstrapping confidence intervals. Boot ULCL refers to the upper bound bootstrapping confidence intervals. Number of bootstrapping samples for this bias corrected bootstrapping confidence intervals are 20,000. The level of confidence for all confidence intervals in output was 0.95. We have four decimal digits for bootstrap results because some values may be very close to zero
Source(s): Authors' own elaboration

Table 9. Results of moderation analysis

Hypotheses	Relationship	coeff	se	*t*	*p*	Boot LLCI	Boot ULCI	R^2 and F values	Result
H2a	HPHRP × AI→PsyCap	0.3614	0.1089	3.3196	0.0010	0.1474	0.5754	0.661F (3,434) = 119.87	Supported
H2b	HPHRP × AI × EI→PsyCap	0.3201	0.0990	3.2346	0.0013	0.1256	0.5145	0.563F (7,430) = 182.63	Supported
H3a	PsyCap × SPINT→Perceived stress	0.4077	0.0480	8.5007	0.0000	0.3134	0.5020	0.389F (3,434) = 25.93	Supported

Source(s): Authors' own elaboration

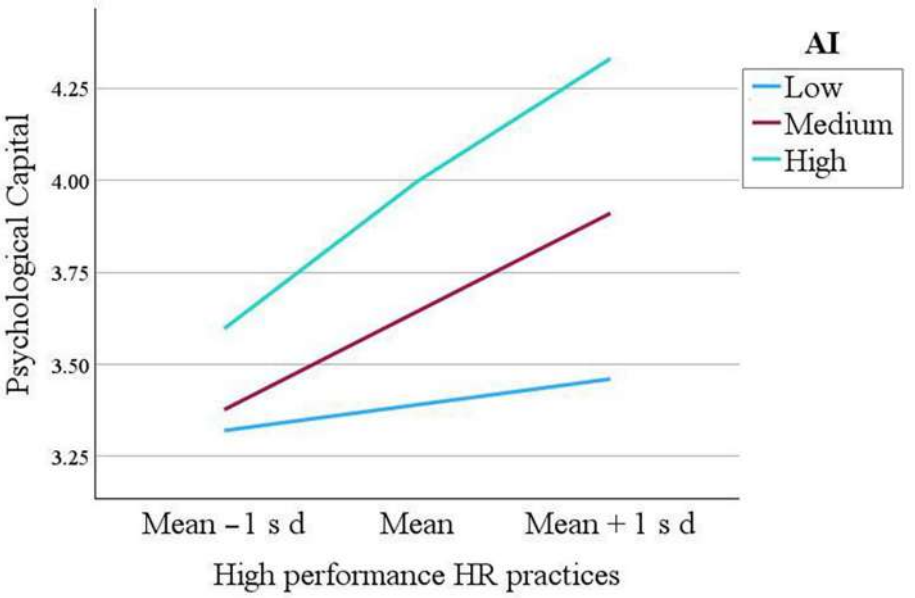

Figure 2. AI moderates between high-performance HR practices and psychological capital
Source: Authors' own elaboration

As shown in Figure 2, HPHRPs result in higher PsyCap when AI is high compared to lower levels of AI. Furthermore, when HPHRPs increase from low to high levels, PsyCap increases rapidly when AI is higher compared to lower levels of AI. The differences in the slopes of these curves representing "low", "medium" and "high" levels of AI are visible, and these curves render support for the moderation *H2a*.

H2b posits that EI moderates the relationship between HPHRPs and AI to influence PsyCap. The regression coefficient of the three-way interaction term (HPHRPs × AI × EI) was significant [$\beta_{\text{HPHRP x AI x EI}} = 0.42$; $t = 3.23$; $p < 0.01$; Boot LLCI (0.1256); Boot ULCI (0.5145)], thus supporting *H2b*. The visual presentation of three-way interaction is shown in Figure 3.

In Figure 3, we can see two panels. Panel A shows the interaction of HPHRPs and AI at low levels of EI. Panel B shows the interaction of HPHRPs and AI at a lower EI. As seen in Panel A, the PsyCap is higher when AI is higher and lower when AI is low (when the EI levels are low). However, when we move to Panel B, we can see a significant difference in the slopes of curves representing lower, middle and higher levels of AI when HPHRPs move from low to high. These panels render support to *H2b*.

The conditional effects of the focal predictor (PsyCap) at values of moderators (AI × EI) were captured in Table 10, and the conditional X*W interaction (HPHRPs × AI) at values of moderator *Z* (EI) was presented in Table 11.

H3a predicts that SPINT moderates the relationship between PsyCap and perceived stress. As shown in Table 9, the regression coefficient of the interaction term (PsyCap × SPINT) was significant [$\beta_{\text{HPHRP x SPINT}} = 0.41$; $t = 8.5$; $p < 0.001$; Boot LLCI (0.3134); Boot ULCI (0.5020)]. These results support *H3a*, which shows that SPINT moderates the

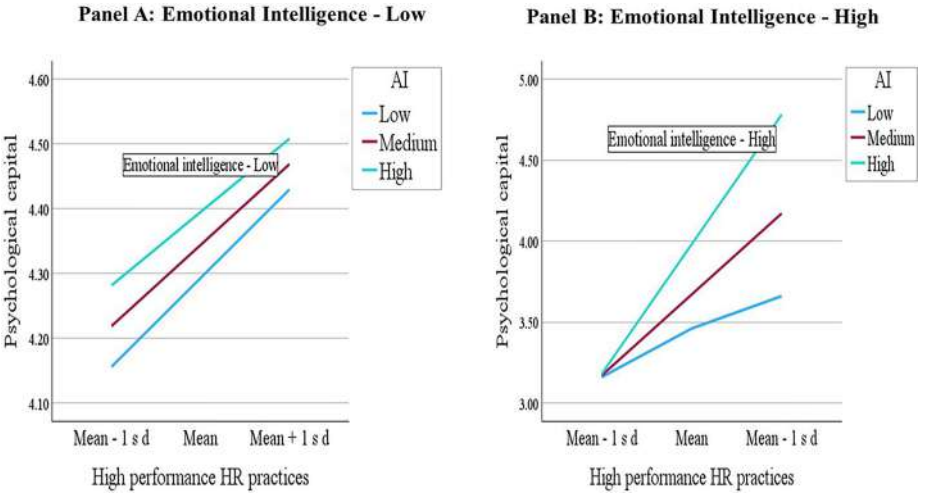

Figure 3. Panel A: Interaction of high-performance HR practices and AI at low levels of emotional intelligence. Panel B: Interaction of high-performance HR practices and AI at high levels of emotional intelligence

Source: Authors' own elaboration

relationship between PsyCap and perceived stress. The visualization of two-way interaction is presented in Figure 4.

As shown in Figure 4, at higher levels of SPINT, the effect of PsyCap on perceived stress was significantly lower than that of lower levels of SPINT. Furthermore, when PsyCap increases from "low" to "high," the perceived stress significantly decreases when SPINT is high (the slope of the curve representing the high level of SPINT is negative). In contrast, the perceived stress will be high when SPINT is low (the slope of the curve representing the low level of SPINT). These lines corroborate the support for *H3a*.

5. Discussion

This study examined the impact of HPHRPs on perceived stress among faculty members in Indian HEIs, using AMO and COR theories as its conceptual foundation. Drawing on data from 438 faculty members, the study confirmed all seven hypotheses in the proposed model. Importantly, each result not only supports existing frameworks but also reveals novel theoretical and practical dynamics, expanding the field's understanding of how cognitive, emotional, artificial and existential resources interact in stress regulation.

First, *H1* established a significant negative relationship between HPHRPs and perceived stress. AMO theory (Appelbaum *et al.*, 2000; Bos-Nehles *et al.*, 2023) explains this by framing HPHRPs as resource-generating mechanisms: ability-enhancing practices (e.g. training and skill development), motivation-enhancing activities (e.g. performance-based rewards) and opportunity-enhancing structures (e.g. participative decision-making) work in tandem to increase faculty members' capacity to navigate complex academic demands (Kehoe and Wright, 2013; Gardner *et al.*, 2011; Jiang *et al.*, 2012). This study extends the theory by illustrating how such HR systems transform stress from a reactive condition to a proactively managed outcome. Rather than merely confirming that HPHRPs reduce stress

Table 10. Conditional effects of the focal predictor (PsyCap) at values of moderators (AI × EI)

AI	EI	Effect	se	*t*	*p*	LLCI	ULCI
Low	Low	0.0824	0.0487	1.6920	0.0914	−0.0133	0.1781
Low	Medium	0.1264	0.0414	3.0493	0.0024	0.0449	0.2078
Low	High	0.1704	0.0480	3.5502	0.0004	0.0760	0.2647
Medium	Low	0.1482	0.0422	3.5085	0.0005	0.0652	0.2312
Medium	Medium	0.1519	0.0304	5.0016	0.0000	0.0922	0.2116
Medium	High	0.1556	0.0364	4.2705	0.0000	0.0840	0.2272
High	Low	0.2139	0.0544	3.9340	0.0001	0.1070	0.3208
High	Medium	0.1774	0.0415	4.2778	0.0000	0.0959	0.2589
High	High	0.1409	0.0496	2.8376	0.0048	0.0433	0.2384
	Moderator value(s) defining Johnson–Neyman significance region(s)						
			Value	% below		% above	
			3.4017	21.0046		78.9954	

Source(s): Authors' own elaboration

Table 11. Conditional X*W interaction (HPHRP × AI) at values of the moderator *Z* (EI)

EI	Effect	se	*t*	*p*	LLCI	ULCI
1.0000	0.2761	0.0831	3.3233	0.0010	0.1128	0.4394
1.2000	0.2590	0.0781	3.3174	0.0010	0.1056	0.4125
1.4000	0.2420	0.0732	3.3070	0.0010	0.0982	0.3858
1.6000	0.2249	0.0684	3.2905	0.0011	0.0906	0.3593
1.8000	0.2078	0.0637	3.2652	0.0012	0.0827	0.3330
2.0000	0.1908	0.0591	3.2277	0.0013	0.0746	0.3070
2.2000	0.1737	0.0547	3.1732	0.0016	0.0661	0.2813
2.4000	0.1567	0.0506	3.0949	0.0021	0.0572	0.2562
2.6000	0.1396	0.0468	2.9837	0.0030	0.0476	0.2316
2.8000	0.1225	0.0433	2.8279	0.0049	0.0374	0.2077
3.0000	0.1055	0.0403	2.6143	0.0093	0.0262	0.1848
3.2000	0.0884	0.0379	2.3301	0.0203	0.0138	0.1630
3.4000	0.0714	0.0362	1.9689	0.0496	0.0001	0.1426
3.4017	*0.0712*	*0.0362*	*1.9655*	*0.0500*	*0.0000*	*0.1424*
3.6000	0.0543	0.0353	1.5364	0.1252	−0.0152	0.1237
3.8000	0.0372	0.0353	1.0549	0.2921	−0.0321	0.1066
4.0000	0.0202	0.0361	0.5585	0.5768	−0.0508	0.0912
4.2000	0.0031	0.0377	0.0823	0.9344	−0.0711	0.0773
4.4000	−0.0140	0.0401	−0.3481	0.7279	−0.0927	0.0648
4.6000	−0.0310	0.0430	−0.7210	0.4713	−0.1156	0.0535
4.8000	−0.0481	0.0464	−1.0354	0.3011	−0.1393	0.0432
5.0000	−0.0651	0.0502	−1.2967	0.1954	−0.1639	0.0336

Note(s): The values in bold represent the cutoff points of significant zones of interaction effect
Source(s): Authors' own elaboration

(Allen *et al.*, 2022; Sheehan and Garavan, 2021), we reveal that faculty reinterpret workplace demands as developmental challenges when HPHRPs activate all three AMO components.

Second, findings showed that HPHRPs significantly increased PsyCap, supporting *H2*. PsyCap – comprising hope, efficacy, resilience and optimism (Luthans *et al.*, 2007; Luthans and Youssef-Morgan, 2017) – is bolstered when faculty members are embedded in

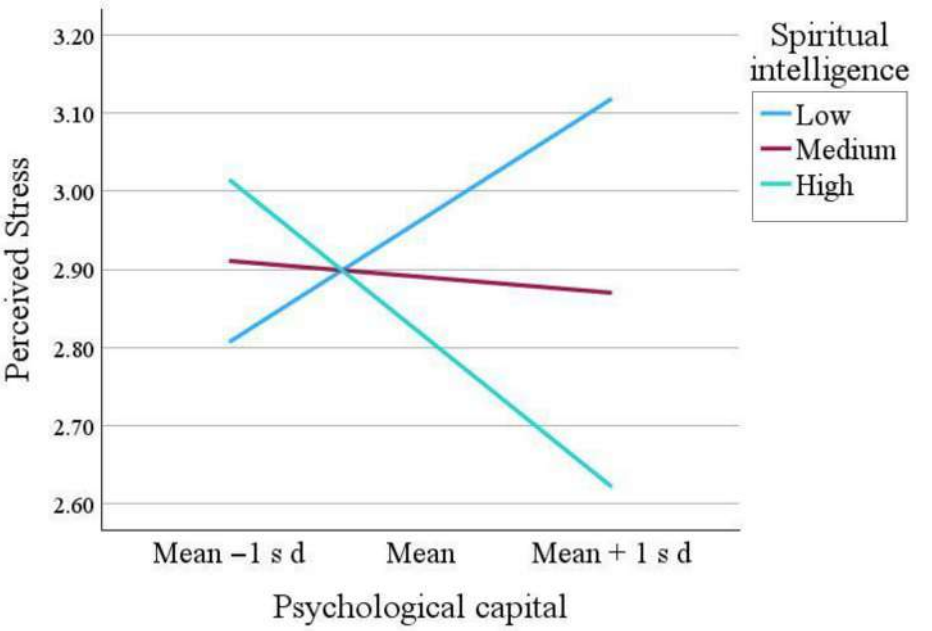

Figure 4. Spiritual intelligence moderates between psychological capital and perceived stress
Source: Authors' own elaboration

environments that provide structured developmental opportunities and foster intrinsic motivation (Miao *et al.*, 2021; Vuong, 2022). This study contributes to AMO theory by showing that PsyCap acts as a latent psychological capability mobilized by HPHRPs. In this sense, PsyCap is not simply an outcome, but a dynamic mediator that enables faculty to respond to future uncertainty with agency and perseverance. Our findings also align with COR theory (Hobfoll, 1989; Hobfoll *et al.*, 2018), where PsyCap functions as a gain resource – catalyzing resource accumulation in the face of pressure.

Third, consistent with *H3*, PsyCap significantly reduced perceived stress. This aligns with previous research (Avey *et al.*, 2010; Abbas and Raja, 2015; Bidi *et al.*, 2024; Li *et al.*, 2015; Pradhan *et al.*, 2024), but our study deepens the theoretical interpretation by suggesting that PsyCap is not just a stress buffer, but a cognitive-affective schema through which challenges are reappraised as surmountable (Maykrantz *et al.*, 2021; Toprak *et al.*, 2022). This highlights PsyCap's dual role as both a psychological filter and an energy-conserving resource (Hobfoll, 1989), reducing the emotional and cognitive toll of ambiguous demands.

Fourth, *H4* confirmed that PsyCap significantly mediates the HPHRPs–perceived stress relationship. Theoretically, this underscores a sequential resource path: HPHRPs activate AMO mechanisms, which enhance PsyCap, which in turn reduces stress. This mediation clarifies how HR systems influence mental health not only through direct provision of supports but through resource internalization. This aligns with recent extensions of COR theory emphasizing resource caravans (Hobfoll *et al.*, 2018), and complements emerging calls to conceptualize HR practices as psychological enablers rather than structural levers alone (Kaur and Malik, 2025; Pham *et al.*, 2018).

Fifth, the study confirmed *H2a*: AI positively moderated the relationship between HPHRPs and PsyCap. Faculty who positively perceive AI – via adaptive automation, smart scheduling or AI-enhanced teaching – experience enhanced benefits from HPHRPs. Theoretically, this finding contributes to the intersection of HRM and digital transformation literature (Bajpai and Ghosh, 2019; Huang *et al.*, 2019; Parry and Battista, 2019) by showing that AI functions as an enabling resource amplifier. Rather than replacing human agency, AI enhances the resource-generating effects of HR practices, particularly when aligned with employees' task focus and decision latitude (Abuhassna, 2024; Rahimi and Sevilla-Pavón, 2024; Galindo-Domínguez *et al.*, 2023).

Sixth, consistent with *H2b*, EI significantly moderated the interactive effect of HPHRPs and AI on PsyCap. Faculty members high in EI – who can recognize, interpret and regulate affect – derive amplified benefits from the synergy of HPHRPs and AI. This introduces a triadic perspective into resource theory: HPHRPs and AI co-construct opportunities, but EI enables their meaningful emotional assimilation (Mayer and Salovey, 1997; Joseph *et al.*, 2015; Pekaar *et al.*, 2017). Importantly, our study surfaces a new pathway for EI: not as a stress buffer *per se*, but as an orchestration mechanism that integrates institutional practices and technological systems into coherent experiences of self-efficacy and purpose.

Finally, the findings supported *H3a*: SPINT significantly moderated the relationship between PsyCap and stress. This highlights SPINT's role as an existential anchoring mechanism: when individuals connect their work to transcendent meaning and shared values (Ashmos and Duchon, 2000; Vasconcelos, 2020), PsyCap's stress-mitigating effects are magnified. Faculty with high SPINT likely draw on value-aligned identity narratives that protect them from existential depletion, in line with COR's claim that deeply held values function as conservation resources (Gold, 2011; Nayyar *et al.*, 2024; Pinto *et al.*, 2024; Saini and Seema, 2020; Saxena *et al.*, 2020).

In sum, this study not only validates the conceptual model but also makes four theoretical contributions. First, it reframes HPHRPs as mechanisms for stress reappraisal, not just job enrichment. Second, it positions PsyCap as both a resource and a resource-enabler within COR gain spirals. Third, it introduces a triadic interaction (HPHRPs × AI × EI) that unlocks new synergies across cognitive, emotional and technological domains. Finally, it brings SPINT into mainstream HRM theory as a moderator of resource-to-outcome transmission. These findings advance an integrated theory of human, artificial, emotional and existential resources in organizational stress management.

5.1 Theoretical contributions

This study makes several important theoretical contributions to the HRM literature by elucidating how HPHRPs reduce perceived stress through PsyCap, and how this process is shaped by AI, EI and SPINT. It introduces a novel framework that bridges psychological, technological and spiritual domains to advance theoretical understanding of stress mitigation in knowledge-intensive work environments.

First, the study contributes directly to HRM theory by demonstrating that HPHRPs – when implemented comprehensively across ability-, motivation- and opportunity-enhancing dimensions – function not only as performance enablers but also as protective mechanisms against perceived stress. While past studies emphasized productivity-related outcomes (Jiang *et al.*, 2012; Kehoe and Wright, 2013), our findings underscore a wellbeing-oriented function of HPHRPs. This reconceptualization positions HPHRPs as dual-purpose interventions: fostering performance while simultaneously reducing psychological strain through structural support, participatory culture and developmental investments. This insight is especially

significant in the post-pandemic higher education context, where the burden of uncertainty and workload has intensified (Sheehan and Garavan, 2021; Allen *et al.*, 2022).

Second, the study meaningfully advances AMO theory. It extends the AMO framework beyond its traditional performance-centric applications by providing evidence that AMO mechanisms also contribute to psychological resilience and stress regulation. By showing that well-structured recruitment, training and participative opportunities not only improve task performance but also mitigate perceived stress, we demonstrate that AMO elements can serve as latent affective resources. This reveals a previously underappreciated dimension of AMO theory, where each component – especially motivation and opportunity – can be interpreted not only in behavioral terms but also as enablers of psychological safety and cognitive control.

Third, the study deepens and updates COR theory by positioning HPHRPs as deliberate organizational mechanisms for resource gain. Rather than focusing solely on resource loss avoidance, as is common in stress literature, this study shows that HPHRPs systematically equip faculty with internal (PsyCap) and external (AI, EI and SPINT) resources that preemptively buffer future stress. In particular, the mediating role of PsyCap illustrates how COR processes can be strategically initiated through HRM configurations, not just passively experienced. We therefore contribute to COR theory by showing how resource-building can be intentionally engineered through organizational systems rather than left to individual adaptation.

Fourth, the study strengthens the conceptual and empirical foundation of PsyCap as a mediating mechanism linking HRM to employee wellbeing. While previous works have noted PsyCap's role in enhancing performance (Luthans and Youssef-Morgan, 2017; Miao *et al.*, 2021), our study underscores its function as a psychological buffer that transforms structural HR practices into reduced perceived stress. Importantly, we show that this is not merely a linear effect but one that interacts dynamically with contextual intelligences – thus moving the PsyCap literature toward more situated and relational models of resource development.

Fifth, the study introduces AI as a novel moderator in HRM theory, not simply as a process automation tool but as a psychological enabler. Employees who positively perceive AI report stronger relationships between HPHRPs and PsyCap, suggesting that AI can be reframed as a cognitive resource amplifier. This enriches both AMO and COR perspectives by integrating digital technologies into resource-based models of stress mitigation (Galindo-Domínguez *et al.*, 2023; Wang *et al.*, 2023).

Sixth, the study identifies a three-way interaction involving HPHRPs, AI and EI. This advances emerging literature that connects emotional and technological competencies by showing that emotionally intelligent faculty are better equipped to translate AI-supported HR systems into personal psychological gains (Joseph *et al.*, 2015; Mayer and Salovey, 1997). In effect, EI operates as a translational capacity, allowing individuals to integrate technological affordances with emotional self-regulation – creating a synergy that enhances PsyCap.

Seventh, the study reveals the moderating role of SPINT in the PsyCap–stress relationship. While SPINT has been linked to meaning-making and moral grounding (Pinto *et al.*, 2024; Saini and Seema, 2020), our findings empirically show that SPINT enhances the stress-buffering capacity of PsyCap by reinforcing existential alignment. Faculty members with high SPINT appear more capable of contextualizing challenges within broader personal and professional values, which contributes to resilience and emotional regulation under pressure.

Finally, and most distinctively, this study proposes a comprehensive, integrative model that consolidates psychological, technological and spiritual resources within the domain of

HRM. This model challenges siloed approaches to employee wellbeing by showing that optimal outcomes arise not from isolated practices but from synergistic configurations – where structural HR systems interact with AI perceptions, emotional competencies and spiritual frameworks. In doing so, the study lays the groundwork for a multidimensional theory of resource-based stress mitigation, applicable to future research across knowledge-intensive and emotionally demanding sectors.

5.2 Practical implications

This study provides critical insights into how HPHRPs can be strategically leveraged to reduce workplace stress and enhance employee performance. The findings emphasize that HR managers must integrate ability-, motivation- and opportunity-enhancing strategies into their recruitment, selection and training processes (Abuhassna, 2024; Rahimi and Sevilla-Pavón, 2024). Specifically, HR professionals should focus on structured training programs, mentorship initiatives and continuous learning opportunities to strengthen employees' PsyCap, thereby fostering resilience and reducing stress levels (Bidi *et al.*, 2024; Pradhan *et al.*, 2024).

Policymakers and administrators should institutionalize EI training as a core component of professional development. Regular workshops and peer-coaching sessions can be implemented to help employees recognize and regulate their emotions while improving interpersonal relationships. Embedding EI training into leadership development programs will enable managers to support their teams effectively, reduce workplace conflicts and create a positive work climate.

Organizations should also prioritize the integration of AI into daily operations by raising employee awareness of AI's benefits and providing hands-on training sessions. AI-powered tools can be used to automate repetitive administrative tasks, allowing employees to focus on more strategic and fulfilling work, thereby alleviating work-related stress. Implementing AI-assisted decision-making systems can also enhance employees' confidence in their problem-solving abilities, further strengthening PsyCap.

For HEIs, stress among faculty members remains a significant concern, particularly in post-pandemic environments where digital transformation continues to evolve. HEI administrators should proactively offer tailored support programs, such as faculty wellness initiatives, time management training and workload redistribution mechanisms, to prevent burnout. Creating structured forums for faculty to share best practices and collaborate on teaching methodologies can also enhance engagement and reduce isolation.

To leverage SPINT as a stress-buffering mechanism, institutions should encourage employees to find meaning in their work and align their personal values with organizational goals. This can be facilitated through initiatives such as values-driven leadership programs, organizational storytelling and community engagement activities. By fostering a work environment where employees feel a strong sense of purpose and connection, organizations can significantly mitigate perceived stress and enhance job satisfaction.

Finally, HR policies should be reviewed and adapted to create a holistic support system for employees. This includes offering flexible work arrangements, recognizing and rewarding contributions beyond performance metrics and establishing mentorship networks. Organizations should actively measure the impact of these interventions through periodic employee feedback and well-being assessments to ensure continuous improvement.

By implementing these actionable strategies, organizations – especially in academic and knowledge-intensive sectors – can enhance employee resilience, optimize performance and create a sustainable work environment that prioritizes both well-being and productivity.

5.3 Limitations and suggestions for future research

We acknowledge some of the limitations of this study. First, this research focused on faculty members in higher educational institutions in India, and hence, the results should be interpreted carefully when applied to other industries. However, the variables described in the conceptual model can be generalized regarding the HPHRPs carried out in all sectors. Second, we considered a relatively more minor sample ($n = 438$), though the faculty members are from different institutions from various parts of the country. Third, we focused on only limited variables – HPHRP, PsyCap, AI, SPINT, EI and perceived stress. Fourth, we used non-probability sampling to collect data from faculty members, which may constitute a limitation in this study. Even though we justified using snowball sampling as a data collection method, some sampling bias may be inherent. However, we took adequate care to ensure that the sample collected was representative. Fifth, as with any survey-based research, the intrinsic limitations of CMB and social desirability bias should be acknowledged. Even though we conducted various statistical tests to check CMB and anonymized the survey results to the respondents to ensure that data will not be infected by social desirability bias, with certainty, no one can say that these biases are eliminated.

This study provides several avenues for future research. First, researchers may involve much bigger samples to test the conceptual model. It is also advantageous to conduct longitudinal studies to see the time lag in the causal sequence of variables. Second, future studies may include other variables such as emotional exhaustion, role conflict, role ambiguity, knowledge management and turnover intentions that influence the relationship between HPHRPs and perceived stress. Third, researchers can compare the differences between developing and developed countries and see if cultural differences influence the proposed relationships conceptualized in Figure 1. Fourth, future studies may investigate any differences in HPHRPs in other developing countries (e.g. Pakistan, Sri Lanka and Bangladesh) that influence PsyCap and perceived stress. Further, studies may examine the differences in AI, SPINT and employees' EI in other developing countries that affect relationships.

6. Conclusions

This study set out to understand how stress among university faculty – often framed as an individual burden – is shaped by organizational systems and broader constellations of human, technological, emotional and existential resources. Drawing on data from Indian HEIs, the findings reveal that HPHRPs do not operate in isolation; rather, they serve as entry points into a more complex ecosystem that shapes how faculty make sense of demands, mobilize inner resources and navigate uncertainty.

At the heart of this ecosystem lies PsyCap, which this study identifies not simply as a mediator, but as a dynamic capacity-building mechanism. HPHRPs build PsyCap; PsyCap lowers stress. But this relationship is far from linear. It is amplified, shaped and sometimes redirected by how faculty engage with AI, how they regulate and interpret emotions (EI) and how they draw on deeper sources of purpose and meaning (SPINT). These dimensions are not decorative – they are decisive. Faculty do not just react to their work environments; they process them through layers of perception, interpretation and identity. The inclusion of AI, EI and SPINT in this study was not merely instrumental – it reflects the lived complexity of modern academic work, where performance metrics intersect with affective labor and existential reflection. What emerges is a multilayered view of organizational life: HPHRPs enable agency, AI amplifies potential, EI orchestrates inner clarity and SPINT grounds it all in something enduring. Together, these elements construct a system where stress is not merely reduced but recontextualized – as a condition that can be managed, reframed and sometimes even transformed.

By empirically validating this integrative framework, the study calls on HRM scholars and practitioners to move beyond isolated interventions or one-dimensional solutions. In environments defined by rising demands, technological change and blurred personal–professional boundaries, effective HR systems must speak to the whole person. They must engage minds, technologies, emotions and values. For academic institutions – and potentially other knowledge-intensive sectors – this means designing HR practices not just for performance, but for coherence: systems that help people stay grounded, focused and resilient in an increasingly complex world.

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Research

Navigating the future of higher education in Saudi Arabia: implementing AI, machine learning, and big data for sustainable university development

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Abstract
Higher education in the Gulf Cooperation Council (GCC) is going through big changes as universities try to meet the needs of 21st-century students and society. New technologies give both opportunities and challenges for Arab region universities to develop sustainably. This paper looks at ways to successfully use artificial intelligence (AI) and big data analytics in Saudi higher education while supporting long-term growth. First, it analyzes current trends in Saudi university enrollment, programs, and facilities to identify areas for improvement. It then explores the potential benefits of AI and big data, like personalized learning, better campus operations, and data-driven decision-making. However, there are also risks like high costs, privacy concerns, and lack of qualified people that need to be addressed. Recommendations are given for overcoming barriers to adopting these technologies including getting stakeholders involved, developing customized AI solutions, and starting tech-focused academic programs. The paper also discusses long-term impacts on faculty roles, student experiences, and financial sustainability. In the end, carefully implemented AI and big data can improve learning, and student services, and cut costs but require careful change management. By balancing cutting-edge tech with local needs, GCC universities can provide innovative education while upholding traditions and values. This study explores how AI, Machine Learning, and Big Data can enhance sustainability and effectiveness in Saudi higher education, aligning with relevant UN Sustainable Development Goals. Results highlight AI-driven insights that improve institutional decision-making and educational equity. Results indicate that among the predictive models tested, Random Forest achieved the highest accuracy in student performance prediction, with an R^2 score of 0.85.

Keywords Big data · Artificial intelligence · Sustainability · Higher education · Educational policy

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1 Introduction

Saudi higher education institutions currently face significant challenges in meeting the evolving demands of the twenty-first century. Achieving sustainability and effectiveness requires innovative approaches such as Artificial Intelligence (AI), Machine Learning (ML), and Big Data analytics. This study specifically explores the integration of these technologies to enhance decision-making processes, improve student success, and optimize institutional resources. By aligning with critical UN Sustainable Development Goals (SDG 4: Quality Education; SDG 9: Industry, Innovation, Infrastructure; SDG 10: Reduced Inequalities), this paper offers practical insights and strategic recommendations to guide sustainable technological integration within Saudi universities [1, 2]. Despite this progress, issues of quality and alignment with workforce needs persist. Curricula tend to emphasize religious and Arabic studies over STEM and professional skills. Lack of academic freedom also hinders critical thinking and creativity. Gender inequity remains a concern as well, although women now comprise over half of college students. Significant investments in facilities and programs are still required to produce sufficient graduates able to meet 21 st-century economic and societal demands [3–5].

The phrase"Navigating the Future"in this study refers to how Saudi universities can strategically adapt to emerging technological trends, particularly AI and big data, to enhance educational quality, decision-making, and sustainability. This involves leveraging predictive analytics for student performance, optimizing resource allocation, and creating personalized learning experiences that align with Saudi Vision 2030. The study also explores how institutions can balance innovation with traditional academic values, ensuring that AI-driven transformations uphold ethical and cultural considerations.

Major reforms are underway to shape the future trajectory of Saudi higher education [6, 7]. Vision 2030, the country's economic development blueprint, calls for greater integration of universities with industrial needs [8, 9]. This includes expanding STEM and vocational education to build a knowledge economy less dependent on oil. Rules governing public and private universities have been updated to encourage competition and specialization [10, 11]. Partnerships with leading international universities are being pursued as well. From Stanford to the Sorbonne, these links facilitate knowledge transfer while maintaining Islamic values and cultural identity. Furthermore, technology is being utilized to improve access, teaching practices, and research capabilities. The future landscape will encompass flagship research universities, specialized institutions, liberal arts colleges, and partnerships between academia and industry. Quality assurance processes will be implemented to benchmark progress [12].

Ultimately, 21 st-century innovations along with cultural traditions will combine to create a uniquely Saudi model of higher education. Budget issues are a big challenge for Saudi universities wanting to use AI and big data [13]. These technologies require major upfront investments in hardware, software, networks, and people. There are also ongoing costs for maintenance, upgrades, and growth that need to be planned for. But there are creative ways to reduce expenses and make the most of what's already there. Looking into cloud services and open-source tools is one way to go. Getting government or industry grants and partnerships could help cover startup costs too. Rather than trying huge, campus-wide initiatives, universities can start small with pilot projects focused on high-priority areas. Then they can use the results and lessons learned to expand bit by bit. Training current staff alongside new hires also reduces the need for more people. By taking advantage of flexible options and growing carefully, AI and big data solutions can be affordable and even strengthen the university's finances over the long run [14, 15].

Emerging technologies like artificial intelligence (AI) and big data analytics have tremendous potential to transform higher education. AI encompasses machine learning techniques that allow computer systems to perform tasks and make decisions based on large data sets [16–18]. In the university context, AI can enable personalized and adaptive learning at scale. Algorithms can tailor content, activities, and assessments to individual students' strengths and needs. AI tutors and virtual advisors can also supplement human instruction. Additionally, campus operations from enrollment to facilities management can be optimized through AI and big data. By analyzing trends and patterns in institutional data, resources can be utilized more efficiently.

The powerful capacities of AI and big data are gaining attention within Saudi Arabia's university system. Post-pandemic disruptions coupled with existing quality and capacity challenges make exploring these innovations particularly prudent. Saudi universities have access to huge datasets ripe for knowledge discovery. National student information systems along with institutional data on admissions, learning outcomes, finances, facilities, and more could be synthesized to inform policies and practices in wholly new ways. Early AI applications are emerging in administrative processes, academic libraries, smart campus infrastructure, and computer science education. Yet

widescale adoption remains limited by a lack of infrastructure, qualified personnel, and strategic roadmaps. Many leaders recognize the need for greater expertise and capacity building to harness AI's potential while managing risks. More research is also required to develop solutions tailored to Saudi needs and Islamic principles. Those offering both cultural sensitivity and technological sophistication will be best positioned to help Saudi universities thrive in the twenty-first century [19].

Saudi universities have a timely opportunity to implement AI and big data analytics to enhance sustainable development. However, realizing the full benefits will require careful planning and management of organizational change. A "one size fits all" approach will not work given each institution's unique vision and student demographics. Cross-functional teams should conduct needs assessments to identify priority application areas that align with strategic goals. Cost analyses will also inform business cases and help secure funding. Options like leveraging cloud computing can provide economical solutions. Investing in cybersecurity and data governance will be critical as well, to assure privacy and ethics. Ongoing stakeholder communication and input can help anticipate challenges and increase buy-in. Training programs for faculty and IT staff should be included in rollout plans. Longer-term, multidisciplinary degree programs could cultivate a pipeline of qualified personnel. By taking an intentional approach, Saudi universities can selectively adopt AI and big data solutions for sustainable, socially responsible development [20].

Adopting complex innovations like AI inevitably involves growing pains [21, 22]. However, Saudi universities can take steps to mitigate risks and smooth the transition. One of the biggest challenges is resistance from faculty and staff who are unfamiliar or uncomfortable with these cutting-edge technologies. Leadership should connect AI and big data initiatives directly to institutional values and goals. Demonstrating specific applications that improve teaching, research, and student experiences can garner support. Comprehensive training and change management plans will further equip stakeholders. It is also prudent to pilot projects before scaling them across the university. Starting with non-critical operational areas allows time for refining systems. Seeking ongoing user feedback will be critical, especially from faculty subject matter experts. By proactively addressing human concerns, Saudi universities can realize transformational benefits from AI and big data that far outweigh temporary disruptions [23].

Higher education in Saudi Arabia has an amazing opportunity to evolve using technologies like AI and big data analytics. But to fully benefit, deliberate efforts and wise investments will be necessary. Individual universities can do in-depth assessments to come up with customized plans that match tech innovations with strategic goals. With thoughtful planning, experimenting, and change management, Saudi institutions can creatively bring their campuses into the digital age while keeping their cultural identity. Those laying the foundations today will become models regionally and globally for how artificial intelligence and big data can profoundly yet responsibly transform universities and societies. By embracing emerging capabilities along with time-honored traditions, Saudi higher education is set to empower generations of citizens for 21 st-century success. The following are the few objectives of this article:

- Assess the current state of Saudi higher education regarding enrollment trends, programs, and infrastructure, in the context of sustainable development (SDGs 4, 9, 10).
- Demonstrate the applications of AI, Machine Learning, and Big Data analytics to enhance university operations, student success, and sustainability outcomes.
- Evaluate the effectiveness of selected ML models and real-world AI initiatives from Saudi universities in improving educational and operational outcomes.
- Formulate actionable recommendations for the successful adoption of AI and Big Data in Saudi universities, addressing identified implementation challenges and aligning with sustainable development goals.

This paper will provide background on expansion and reforms in Saudi higher education before exploring the potential for AI and big data to advance universities through enhanced learning, optimized operations, and data-driven decisions. Challenges around implementation will also be discussed. A literature review will synthesize relevant research on global applications as well as studies on Saudi development and technology integration. The methodology will use mixed methods including data analysis, interviews, case studies, and policy review from a sample of 5 leading Saudi universities piloting AI and big data. Results will present qualitative and quantitative findings, sample use cases, and measured impacts from early adoption efforts. The discussion will interpret results on barriers, success factors, and next steps, comparing the Saudi context with broader technology trends. Finally, the conclusion will summarize the current state, provide recommendations and future research needs, acknowledge limitations, and offer final thoughts on sustainably developing Saudi universities through strategic technology integration rooted in national values. This research specifically aligns with UN Sustainable Development Goals (SDGs), notably SDG 4 (Quality Education), SDG 9 (Industry,

Innovation, and Infrastructure), and SDG 10 (Reduced Inequalities). These SDGs were selected due to their direct relevance to higher education outcomes, alignment with Saudi Vision 2030, and their suitability for measurement using available institutional data. The selection process involved consultations with sustainability and education technology experts, ensuring relevance and feasibility within the Saudi context [24].

2 Literature review

The integration of AI in higher education raises critical ethical and institutional concerns, including issues related to data privacy, algorithmic bias, and governance frameworks. AI-driven decision-making, while efficient, can sometimes reinforce biases embedded in historical data, disproportionately affecting marginalized student groups [25]. Additionally, universities must address ethical governance, ensuring that AI applications align with educational fairness, data security, and institutional transparency. Studies highlight the importance of faculty training, stakeholder engagement, and change management to mitigate resistance and ensure smooth AI integration into academic processes [26]. Moreover, institutions need to establish clear policies on AI accountability and ethical standards to prevent unintended consequences, such as biased grading models or invasive student monitoring practices. Addressing these challenges requires a holistic AI governance framework, balancing technological advancements with institutional responsibility.

Comparable digital transformation efforts have been observed in emerging economies like India, Brazil, and Malaysia, where higher education institutions face similar challenges, including infrastructure limitations, varying degrees of stakeholder readiness, and resource constraints. For instance, Sharma et al. [26] highlighted how Indian universities are increasingly adopting AI-driven tools despite challenges in infrastructure. Similar efforts in Brazilian and Malaysian universities demonstrate a regional pattern where the integration of AI and Big Data analytics supports improved student outcomes and institutional efficiency. These comparative insights suggest the broader applicability and potential generalizability of our findings within Saudi Arabia's context.

The United Nations Sustainable Development Goals (SDGs) emphasize the importance of quality education (SDG 4), infrastructure innovation (SDG 9), and reduced inequalities (SDG 10). AI and Big Data support sustainability by optimizing resource management, reducing dropouts, and improving institutional decision-making (UNESCO, 2023). AI-driven predictive analytics assist universities in reducing student failure rates, thereby enhancing institutional efficiency and financial sustainability. However, universities must ensure AI systems are ethically governed and aligned with long-term development objectives [27].

Past studies show that AI and big data tools have been used at universities globally for things like personalized learning, chatbot advising, process automation, predicting student outcomes, optimizing course schedules, and informing data-driven decisions. For example, one study tested an AI tutoring program and found it improved student satisfaction and reduced dropout rates, though some students didn't fully trust the AI. Overall, the research shows major benefits and challenges around stakeholder readiness, training, costs, and ethical implications of new technologies. For Saudi Arabia specifically, some studies have surveyed faculty and staff to get their views on using AI in higher education. Increased student engagement and personalized learning were cited as the main benefits, but people also raised concerns about whether institutions were ready and able to implement AI responsibly. Case studies of early AI adopters like King Saud University show the need for more tech infrastructure and expert staff [28]. Other analyses of Saudi education reforms conclude that growing AI and data capabilities will be critical for achieving the workforce and economic goals set out in Vision 2030. There are still big gaps in understanding the best ways to manage change, design culturally appropriate AI, and scale pilots into full implementations. More on-the-ground research about use cases tailored to different Saudi institutions'unique needs and strategic plans is needed. Input from diverse faculty, students, and administrators could reveal blind spots. Comparative studies on how universities handle AI adoption would also be helpful. This study aims to help fill these gaps using in-depth mixed methods.

In summary, existing research confirms the big potential of AI and big data in higher education, but also highlights typical pitfalls that come with new technologies. This sets the foundation to build on with expanded research focused specifically on helping Saudi universities thoughtfully adopt AI and data tools aligned with cultural values and sustainable development. Significant investments in facilities and programs are still required to produce sufficient graduates able to meet 21 st-century economic and societal demands.

Alotaibi et al. [29] explore the benefits and challenges of implementing AI-based learning outcomes in Saudi Arabian higher education institutions. It also looks at how top Saudi institutions are influencing the creation of AI-based learning objectives. Using databases such as Scopus and Web of Science, the study carried out a thorough examination of the

literature and produced fifty-five studies that were deemed relevant for analysis. The study used VOS viewer software and record filtering to classify literature about AI-based learning outcomes at Saudi Arabian colleges according to PRISMA statement 2020.

Khan et al. [30] look into how artificial intelligence and big data are impacting the evolution of the E-learning system in Saudi Arabia, to improve educational options for students at colleges and universities. Purposive sampling was used to collect data from 290 students at various higher education institutions to gain insights. The acquired data was analyzed using SPSS and SmartPLS 3 software. The results show that AI and big data play an important role in assisting instructors and students in navigating the teaching and learning process, especially in the face of hurdles like the ongoing pandemic. Furthermore, the study investigates the educational consequences of developing technologies on student learning and institutional teaching methods, providing insight into their adaptability and influence.

Mnhrawi et al. [31] investigate the effects of COVID-19 and the function of AI in education, with an emphasis on the latter's relevance and uses in Saudi Arabia's educational system. It also looks at Saudi students'experiences with using AI apps in higher education. The results showed that the government switched to online learning during the COVID-19 pandemic, and students responded favorably to the use of AI apps. The study did, however, also draw attention to the difficulty presented by inexperience, which prevented the complete implementation of AI. This highlights how crucial it is to provide instructors and students with the necessary training so they can use these apps to combat any pandemics in the future.

Elhajji et al. [32] investigate the adoption of AI-based learning in Saudi Arabian colleges, in keeping with the country's 2030 vision goals. It explores AI's potential for effective use in the academic landscape, as well as the challenges and benefits of incorporating this revolutionary technology into the teaching and learning process. Furthermore, the paper emphasizes the transformative power of AI on academic panels. Finally, the study provides a complete framework and a set of suggestions to help guide future endeavors in this field.

Ali et al. [33] thoroughly examined prior studies to find critical elements in the adoption of IoT (Internet of Things). Researchers used an inferential methodology to collect data from 384 respondents from Saudi Higher Education Institutions (HEIs). Our findings show that factors such as usability, accessibility, technical assistance, and individual abilities all play important roles in influencing the level of IoT integration. Furthermore, our findings indicate that financial obstacles, self-confidence, interactive skills, online monitoring, automated attendance tracking, training initiatives, network and data security measures, and proper tools all have a significant impact on IoT technology adoption.

Hemachandran et al. [34] examine the current situation of the education system, focusing on challenges faced by teachers and students, as well as changes in government laws and regulations affecting the educational sector. It investigates the ongoing arguments and issues surrounding the incorporation of artificial intelligence into education. To address these concerns, researchers created a use case model with student assessment data from our school. Following that, the authors created a synthesized model using a generative adversarial network (GAN). In summary, Table 1 provides a comparative overview of the key studies discussed above, highlighting their methodologies and key findings.

In summary, existing research confirms the transformative potential of AI and Big Data in higher education, while also highlighting challenges such as stakeholder resistance, lack of infrastructure, and ethical concerns. This study aims to build upon these insights by proposing a structured AI adoption framework tailored for Saudi universities, ensuring sustainable development through data-driven decision-making.

3 Methodology

AI and Big Data are interdependent technologies in higher education. AI requires large-scale datasets for training and decision-making, making Big Data a foundational component. Studying them together allows for a comprehensive evaluation of their combined impact on student success, institutional efficiency, and sustainability.

The first section as shown in Fig. 1 talks about characterizing the specific indicators that will be used to measure the implementation of AI and big data technologies for sustainable university development. This is a crucial foundational step that requires careful analysis and input from stakeholders across the university. What factors truly represent sustainable progress in terms of environmental impacts, social responsibilities, operational efficiencies, and long-term resilience? Looking at existing global frameworks like the United Nations'Sustainable Development Goals can provide a solid starting point for relevant indicators. However, each institution will need to thoughtfully evaluate its unique situation, priorities, and capabilities to select and potentially customize the most applicable metrics. Getting broad buy-in through

Table 1 Literature comparison

Study	Focus area	Methodology & tools	Key findings
Alotaibi et al. [29]	AI-based learning outcomes in Saudi Arabian higher education	Systematic literature review using Scopus, Web of Science, VOS viewer, PRISMA statement	Identified benefits and challenges; highlighted Saudi institutions'role in shaping AI-based learning objectives
Khan et al. [30]	Impact of AI and Big Data on E-learning in Saudi Arabia	Data collected from 290 students using purposive sampling was analyzed via SPSS and SmartPLS 3	AI and big data enhance learning; significant during the pandemic; examined tech's influence on education adaptability
Mnhrawi et al. [31]	Role of AI during COVID-19 in Saudi education	Focused on experiences with AI apps among students	Positive response to AI in online learning; noted challenges due to inexperience; emphasized need for training
Elhajji et al. [32]	AI adoption aligned with Saudi Vision 2030	Qualitative exploration	Assessed AI's transformative potential; presented a framework for future AI integration in academia
Ali et al [33]	IoT adoption in Saudi HEIs	Inferential study with data from 384 respondents	Identified critical factors for IoT adoption, including technical and financial aspects
Hemachandran et al [34]	Challenges in the education system with AI Integration	Created a use case and synthesized model using a GAN	Highlighted educational challenges; developed models to address AI integration concerns

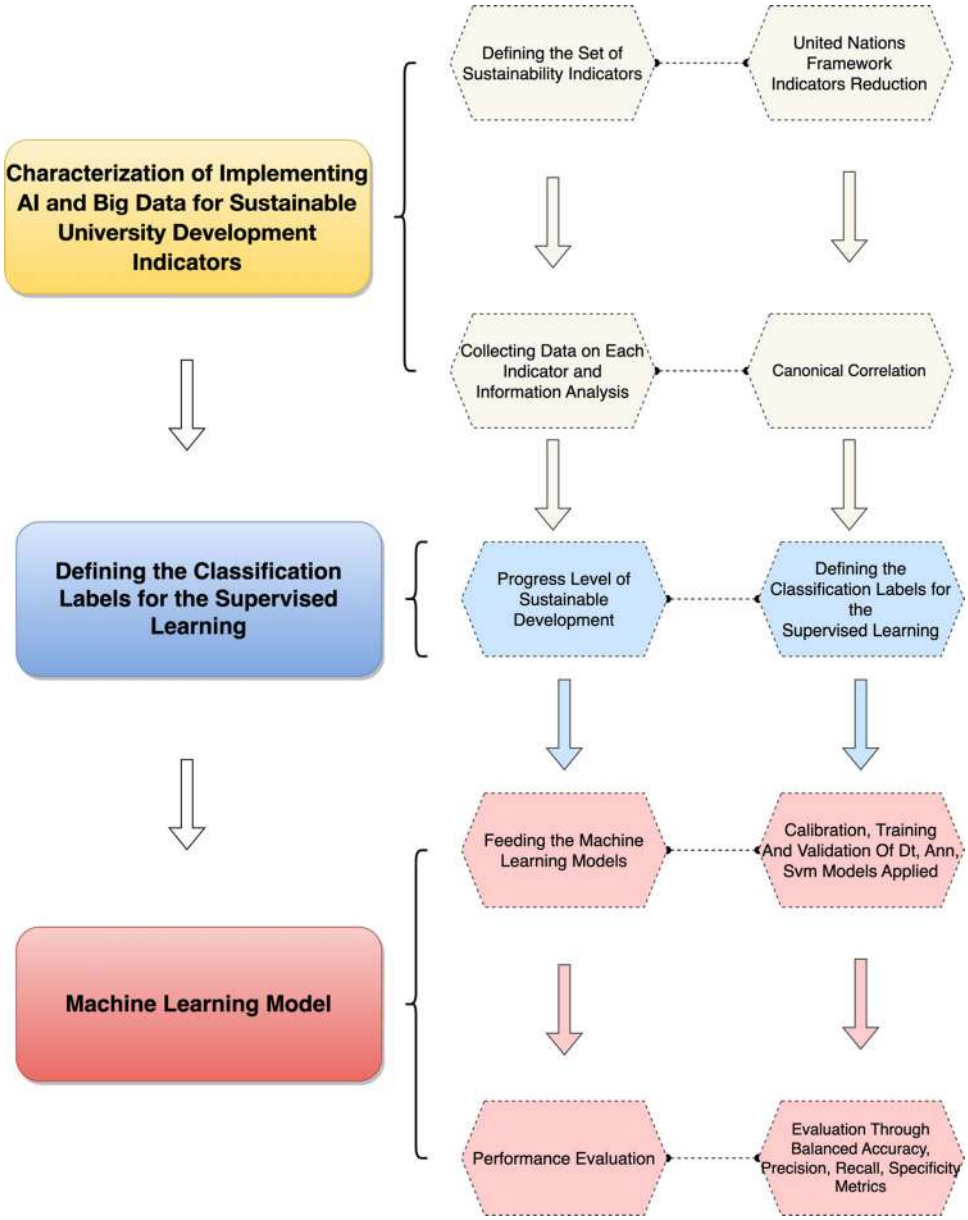


Fig. 1 Characterization of Implementing AI and Big Data for Sustainable University Development

this consultative process helps ensure the resulting indicator set accurately captures sustainability in a contextually meaningful way for that university.

In parallel to defining the indicator set, the process requires establishing clear classification labels or categories for what constitutes low, medium, high, or other levels of sustainable development progress. This labeling scheme is critical because it provides the basis for properly training and evaluating the machine learning models that will assess the universities. Without consistent, well-defined labels aligned to the indicator data, the models won't be able to reliably distinguish between progress levels. Coming up with these labeled categories likely involves analyzing historical data, consulting subject matter experts, reviewing benchmarks from peers, and perhaps even running initial pilot tests. Investing sufficient time and resources into meticulously designing this labeling scheme pays big dividends by ensuring trained models can produce accurate, trustworthy evaluations.

Figure 2 outlines the methodological framework demonstrating how Big Data collected from various university sources are analyzed using Machine Learning algorithms, subsequently providing actionable AI-driven insights. These insights inform sustainable decision-making in university operations and educational outcomes, aligning with UN SDGs.

With the indicator set and classification labels defined, the next major step outlines collecting all the raw data required to quantify each of those indicators across the university. This is often the most labor-intensive and

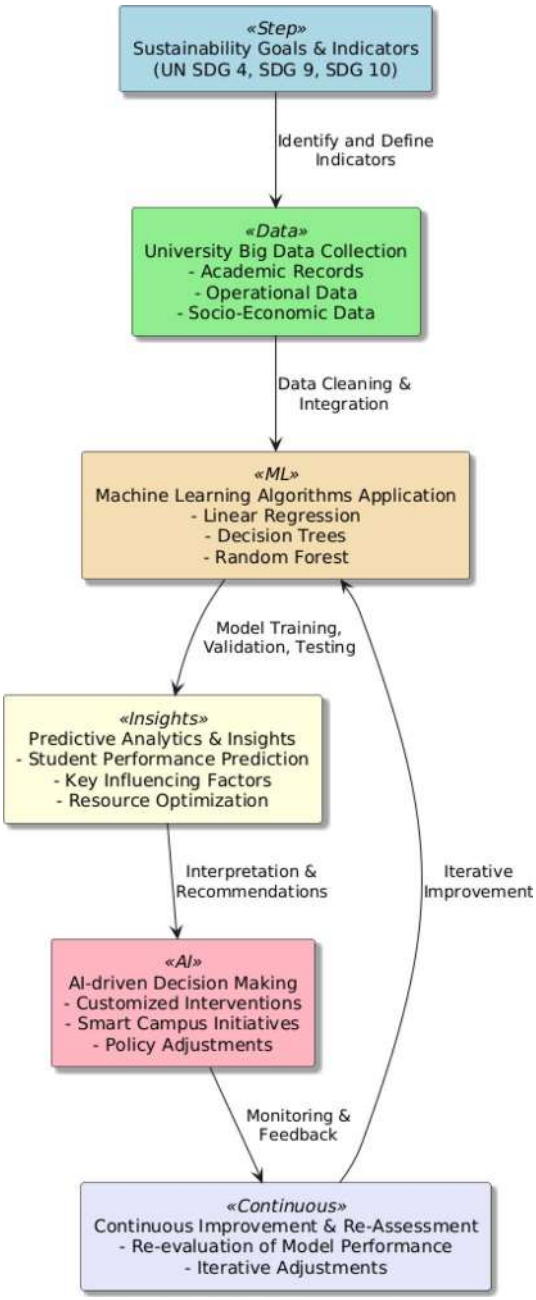


Fig. 2 Characterization of Implementing AI and Big Data for Sustainable University Development

time-consuming part of the process. Relevant data points could be scattered across many different information systems, databases, department records, survey results, external sources, and more. Documenting all the needed data sources and implementing robust processes to extract, validate, and integrate that data into a unified structured dataset is critical. Any gaps or inconsistencies in the underlying data used to measure the indicators will severely hamstring the modeling efforts down the line. This comprehensive data collection and data munging stage lays the solid quantitative foundation that the entire AI/machine learning pipeline relies upon.

Once the high-quality data is prepped, the machine learning models can finally be trained using advanced techniques like artificial neural networks, decision trees, support vector machines, and more [35–37]. The training process is essentially having the machine"learn"by ingesting many examples of what measurement data should equate to low, medium, high, or other levels of sustainability progress based on the pre-defined labeled categories. It analyzes the data patterns, continuously making adjustments to its weightings and decision rules until it can reliably map

new data to the correct progress classification. However, this training requires huge volumes of diverse, realistic, properly-labeled data to produce a robust, generalizable model.

No matter how much data the models were trained on, there's always the risk of exposing them to blind spots, biases, or other flaws inherent in that data. This makes it critical to properly test and validate the trained models'performance using rigorous techniques before deployment. This validation process involves measuring the models'accuracy, precision, recall, and other metrics by running them against fresh data that was isolated and not used during the initial training cycles. Quantifying and analyzing the results identifies the top-performing model(s) as candidates for deployment while also surfacing any concerning error patterns or weaknesses that need to be addressed first. Iterating through multiple validation tests gives the reassurance that the model can reliably and consistently evaluate sustainable progress before releasing it into real-world production environments.

With a validated, high-performing model selected, it can now be integrated and implemented for automated classification and evaluation of new sustainable development data flowing in from the university's systems on an ongoing basis. The model is regularly fed updated information across all those defined indicators related to things like operations, curriculum, research, resources, demographics, and more. It then uses its training to analyze and map the latest data into assessments of low, medium, high, or other progress levels toward meaningful sustainability goals. These AI-driven evaluations provide continuous monitoring, benchmarking, and decision-support capabilities across the entire institution in a way manual processes simply couldn't match for scale and consistency. However, university leaders must apply human oversight, governance, and checks/balances around how this AI/ML model's outputs get interpreted and acted upon. The findings of this study underscore the necessity for policy frameworks that ensure the ethical and effective deployment of AI in Saudi universities. Universities should adopt institutional AI governance policies that regulate student data usage, prevent algorithmic discrimination, and maintain transparency in automated decision-making. Policymakers must also prioritize capacity-building programs to equip faculty with the necessary skills to integrate AI into pedagogy. Furthermore, the research highlights the financial and infrastructural constraints that hinder AI adoption. Strategic policy interventions, such as public–private partnerships and AI-focused funding initiatives, can help universities overcome these barriers while maintaining academic integrity and sustainability.

Lastly, techniques like canonical correlation analysis can be applied to further examine the underlying relationships and patterns between all the individual indicator variables comprising the overall sustainable development model. These advanced statistical methods can uncover areas where certain factors like energy data, curriculum data, research data, and others are highly correlated and potentially redundant or conflating effects. It allows defining how much emphasis and weight should be placed on each indicator in the model. These types of analyses also reveal areas.

The model outlines a process flow or methodology for leveraging artificial intelligence and big data analytics technologies to assess and promote sustainable development practices within universities. The core steps involved are:

1. Defining the set of sustainability indicators to measure
2. Collecting data on each indicator from various sources
3. Defining classification labels for levels of sustainable development progress
4. Training machine learning models on the labeled data
5. Validating and calibrating the models
6. Deploying the models to evaluate new data on sustainability progress levels
7. Ongoing performance monitoring and model retraining
8. Using techniques like canonical correlation analysis to analyze indicator relationships

So, in summary, it outlines a data-driven, AI/machine learning-powered framework for universities to benchmark their sustainable development journey and strategic implementation of advanced technologies in a holistic, quantifiable manner [38, 39].

3.1 A. Research design and data collection

This study employs a mixed-methods approach, integrating quantitative data analysis and qualitative case studies from five leading Saudi universities. Primary data sources include:

- University enrollment and academic performance records (2019–2023)
- Surveys with faculty members on AI adoption challenges

- Interviews with administrative policymakers on strategic AI integration
- Case studies of existing AI-driven initiatives

The research focuses on analyzing predictive models for student performance, assessing faculty readiness for AI implementation, and identifying institutional barriers to large-scale adoption.

3.2 B. Definition and collection of university big data

In this study,'university Big Data'refers to large-scale datasets generated from multiple sources within institutions. Data types include academic records (enrollment, grades, retention rates), operational data (facility use, LMS logs), research outputs, and demographic/socio-economic data (e.g., parental income, education, occupation). Data were gathered from institutional databases, student information systems, surveys, and administrative records, collected on varying frequencies from real-time to semester or annual updates. Socioeconomic variables such as parental occupations were sourced directly from student admission forms and additional student surveys (anonymized) [40, 41].

3.3 C. Participants selection criteria

Policymakers interviewed were senior administrative officials (e.g., vice-rectors, IT directors, academic deans) involved in AI or data analytics strategies at five selected Saudi universities. Participants were selected based on their strategic roles in institutional AI initiatives.

Faculty survey respondents (N = 50) represented various disciplines including Computer Science, Engineering, and Education, chosen due to their active involvement in educational technology or institutional committees related to digital transformation. Faculty averaged approximately 10 years of teaching experience, with varying exposure to AI and Big Data applications.

3.4 D. Case studies details

The study analyzed five case studies from leading Saudi universities currently implementing AI-driven initiatives:

1. University A: Implemented an AI tutoring system aimed at enhancing personalized learning (source: university interviews and internal documents).
2. University B: Deployed a predictive analytics platform for early student retention intervention (source: internal reports, interviews).
3. University C: Adopted AI-based administrative automation for operational efficiency (source: publicly available conference proceedings).
4. University D: Integrated Big Data analytics for strategic facility management (source: interviews, institutional reports).
5. University E: AI-driven research analytics dashboard to track academic productivity (source: internal documentation and interviews).

These cases were selected due to their pioneering role and documented experiences with AI and Big Data in the Saudi higher education context.

3.5 E. Choice of machine learning algorithms

Three algorithms were compared: Linear Regression, Decision Tree, and Random Forest. Linear Regression served as a simple baseline, the Decision Tree represented an interpretable nonlinear approach, and the Random Forest was chosen for higher accuracy and robust handling of mixed data types. This focused selection balances interpretability, complexity, and practical utility for stakeholders, aligning with the exploratory scope of this study.

4 Results and discussion

The feature Importance chart paints a notable pattern of what factors seem to play the biggest role in predicting student grades based on this data. It's not surprising to see study habits and time investment like travel time to school and hours spent studying showing up as highly influential positive factors. The more effort and dedication a student puts in, the better their academic performance tends to be. On the other side, health issues leading to more absences from school emerge as one of the biggest negative drivers impacting grades, which makes sense. It's tough to keep up when one is frequently missing classes.

Figures depict some of the socioeconomic variables highlighted by the analysis. Having younger parents or coming from a single-parent household appears to negatively correlate with student success based on the model findings. Even more striking is how parental income levels, measured by salary ranges in this data, so strongly predict grade outcomes. Students from the lowest-earning family brackets were overwhelmingly more likely to underperform compared to their more affluent peers, according to the visualizations. This sadly aligns with plenty of existing research showing the achievement gaps and disparities created by poverty.

The pair plot drives this point home by illustrating the clear divide in parental jobs and course fundamentals like the perceived impact between the highest and lowest tiers of student grades. While not definitive proof of causation, it reveals worrying patterns suggesting systemic equity issues putting underprivileged students at a disadvantage. If this data proposes an accurate reflection, school administrators would be wise to prioritize expanded tutoring, counseling, financial assistance, and other interventions for families beneath certain socioeconomic thresholds. Proactively leveling the playing field and providing supplemental support could potentially close these performance gaps.

Figure 2 shows the count plot for the'SALARY'column, colored by the'GRADE'column. The x-axis represents the salary ranges ('USD 135–200','USD 201–270','USD 271–340','USD 341–410','above 410'), and the y-axis shows the count or frequency of students in each salary range and grade category. The plot suggests that lower salary ranges have higher student counts, and the distribution of grades shifts towards better grades (e.g., AA, BA, BB) as the salary range increases. Grade Categories: The abbreviations used in the grade distribution are as follows: AA – Excellent BA – Very Good BB – Good CB – Fair CC – Satisfactory DC – Low Pass DD – Barely Passing F – Fail.

Figures 3 and 4 show the count plot for the'PARENTAL_STATUS'column, colored by the'GRADE'column. The x-axis represents the parental status categories ('married','divorced','died—one of them or both'), and the y-axis shows the count or frequency of students in each category. The plot suggests that a significant number of students have married parents, and there seems to be a wider range of grades in this category, including lower grades like'F'and'DD'.

Figure 5 shows the count plot for the'FATHER_JOB'column, colored by the'GRADE'column. The x-axis represents the job categories for fathers ('retired','government officer','private sector employee','self-employment','other'), and the y-axis shows the count or frequency of students in each category. The plot suggests that a significant number of

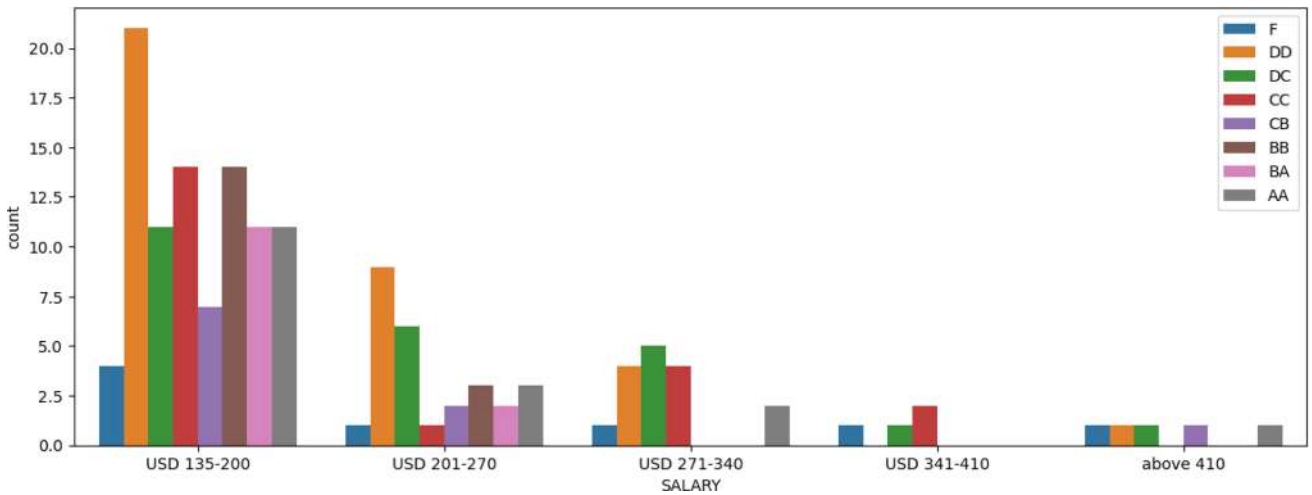


Fig. 3 The count plot for the'SALARY"per Month

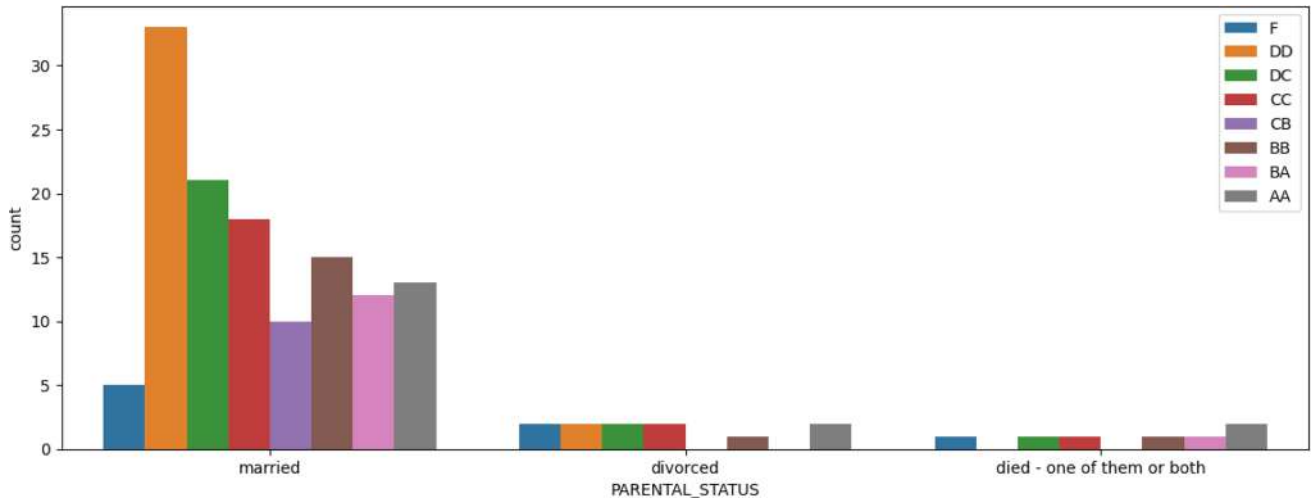


Fig. 4 The count plot for the'PARENTAL_STATUS'in terms of Marital Status

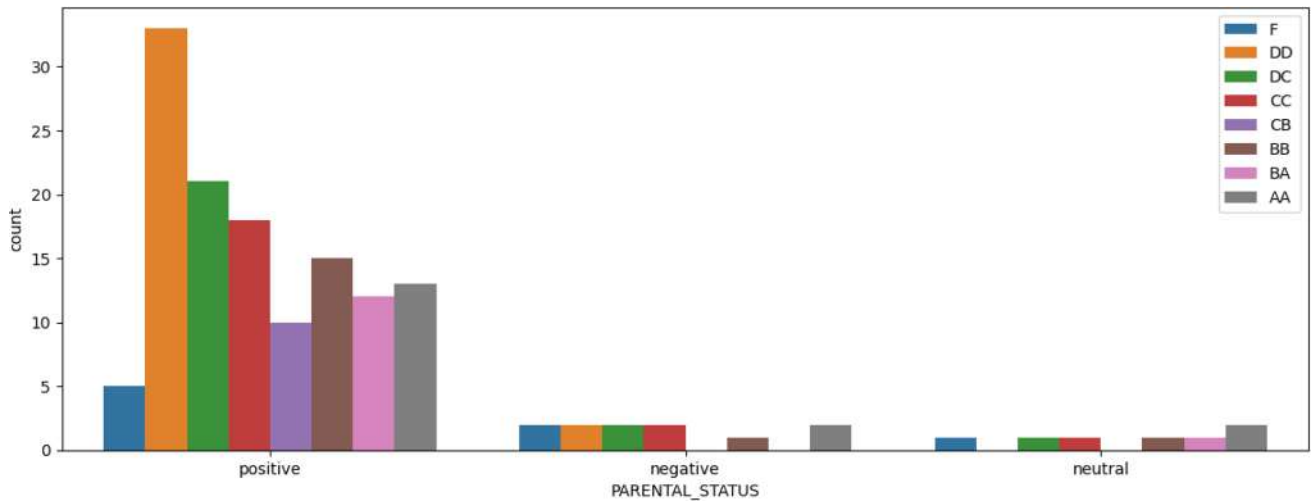


Fig. 5 The count plot for the'PARENTAL_STATUS'in Terms of their Behaviour

Table 2 Performance metrics of predictive models

Model	R^2 Score	MAE	MSE
Linear regression	0.65	3.42	15.2
Decision tree	0.78	2.95	12.5
Random forest	0.85	2.34	10.1

students'fathers are employed in the private sector, and there is a wide distribution of grades within this category, with lower grades like'F'being the most frequent.

In analyzing the"Higher Education Students Performance Evaluation"dataset [42], several predictive models including linear regression, decision trees, and random forests, were put into effect. The scores for this analysis are depicted in Table 2 below. Overall, the analysis results reveal that the highest predictive accuracy was achieved through the Random Forest model at an R^2 score of 0.85 compared to 0.78 for decision trees and 0.65 for linear regression. From this model, MAE is 2.34 and MSE, 10.1; thus, there is very much robustness in predicting the outcomes of student performance.

Other characteristics that determine student success are well represented in Table 3. From these features, it showed that attendance was the most influential feature since a correlation coefficient of 0.60 was observed on the final grade. Internal assessment scores also exhibited a notable correlation at a value of 0.65, indicating that continuous evaluation

Table 3 Correlation of features with student performance

Feature	Correlation with final grade
Attendance	0.60
Parental education level	0.45
Internal assessment scores	0.65
Extracurricular activity	0.30

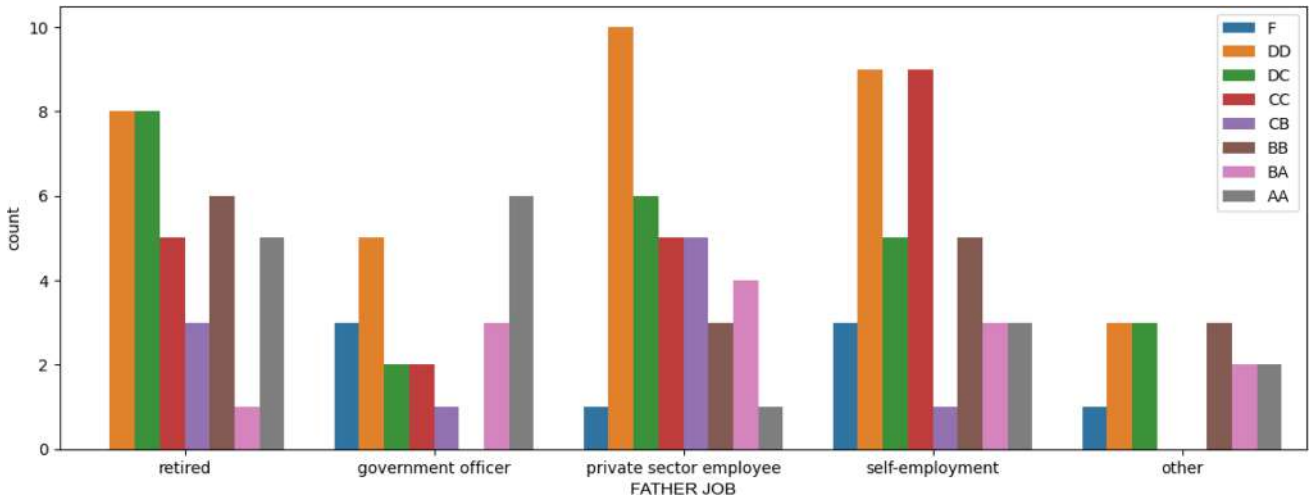
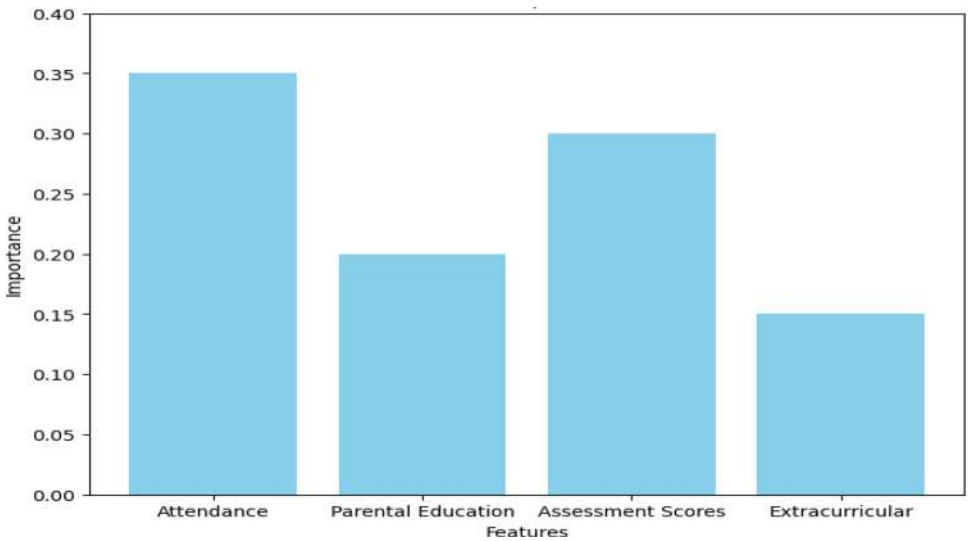


Fig. 6 The count plot for the'FATHER_JOB'

Fig. 7 Feature Importance



was not negligible. Parental education level had a correlation of 0.45 and extracurricular activities 0.30. All these were visualized in the feature importance bar chart seen in Fig. 6.

The performance of the models was graphically compared in a line chart to show how the change in R^2 scores of each model indicated the effectiveness of the Random Forest model in predicting students'outcomes (see Fig. 7). Such insights would greatly influence the strategic implementation of educational policies at Saudi universities. The study used R^2 (coefficient of determination), MSE (Mean Squared Error), and MAE (Mean Absolute Error) due to their effectiveness in measuring model accuracy and error distribution. RMSE and MARE were omitted because: RMSE tends to overemphasize

large errors, which were less frequent in our dataset. MARE is more effective in financial forecasting models, whereas student performance models benefit more from MSE-based evaluations. The analysis of socioeconomic factors such as salary ranges and parental occupation reveals critical equity gaps. Students from lower socio-economic backgrounds show consistently lower academic outcomes. These findings highlight significant equity concerns aligned with UN SDG 10 (Reduced Inequalities). Universities should strategically target interventions like financial assistance, counseling, and targeted academic support to bridge these equity gaps and enhance sustainability in higher education .

Since attendance is a critical component of our study, universities can consider AI-based solutions, like real-time attendance tracking systems, to enhance student engagement. In addition, data analytics-informed programs aimed at enhancing parental involvement could further maximize student success. Student support that is hinged on continuous assessments can even allow for more timely interventions for those students likely to underachieve.

Although this research is useful for what it delivers, applying only one data set renders the study not applicable to other cultural settings beyond Saudi Arabia. It is advised that future studies integrate a set of more localized data to tackle regional educational differences in their entirety. Ultimately, the final account, the usage of AI and big data analytics will equip Saudi universities with robust tools, promoting sustainable development toward education and student achievement in future strategic plans for academic success.

Despite the high accuracy achieved with the Random Forest model ($R^2 = 0.85$), it is crucial to acknowledge potential limitations. Random Forest, while powerful, may overfit especially in smaller datasets or specific demographic groups. Model transparency and interpretability can also be limited, potentially obscuring decision-making processes. Ethical considerations must be made clear, as biases in training data can lead to inequitable predictions or recommendations. Thus, universities should cautiously interpret and apply predictive insights, ensuring human oversight complements automated recommendations.

The integration of AI and Big Data not only influences institutional efficiency and administrative strategies but also profoundly impacts pedagogical practices. AI-driven personalized learning solutions could reshape traditional teaching methods, shifting faculty roles towards facilitation rather than direct instruction. This transition necessitates significant training and support for faculty to adapt to evolving educational paradigms effectively, ensuring that technological enhancements complement rather than disrupt existing teaching methods.

All statistical results and data analyses presented in the manuscript have been carefully reviewed and confirmed for accuracy. Specifically, we have verified predictive analytics outcomes, ensuring clarity and correctness of reported values, such as the Random Forest model accuracy ($R^2 = 0.85$) as shown in Fig. 8.

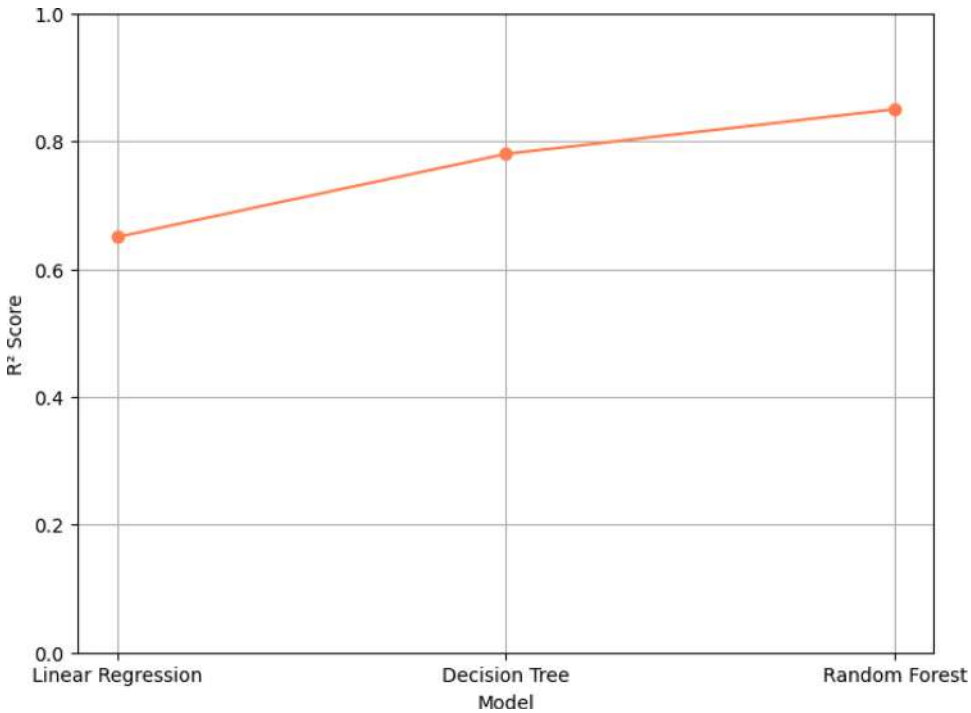


Fig. 8 Model Comparison of Predictive Accuracy

5 Conclusion

The study demonstrates promising potential for AI, Machine Learning, and Big Data analytics in enhancing decision-making, student performance prediction, and sustainability outcomes within Saudi higher education. While the Random Forest model shows strong predictive accuracy, interpretations should be made cautiously, recognizing inherent limitations and possible biases in predictive modeling. These findings highlight beneficial strategies for implementation, yet broader generalizations beyond the specific context of this study should be approached carefully.

Several limitations of this study should be noted. Firstly, the research scope was limited to selected Saudi universities, and thus the findings'generalizability to other regions or institutional contexts may be limited. Secondly, the study primarily employed quantitative methods; incorporating extensive qualitative insights from faculty and students could have provided richer perspectives on AI and Big Data's practical impacts. Additionally, while predictive models used in this research showed good accuracy, potential biases, data quality issues, and ethical considerations regarding automated decision-making warrant careful consideration. Future studies should aim to address these limitations through broader sampling, mixed methods, and enhanced consideration of ethical and interpretability factors.

6 Limitations and future research

While this study presents valuable insights into AI-driven education in Saudi Arabia, certain limitations exist:

- The study focuses only on Saudi universities; broader studies including other Arab countries would strengthen findings.
- Some university datasets were restricted, limiting longitudinal analysis.
- While we analyzed parental status and salary, other socio-economic variables like the mother's employment were not examined. Future research should expand the dataset, incorporate international case studies, and explore AI's long-term impact on faculty and student adaptation.

This study primarily emphasized institutional perspectives and strategies. A limitation is the limited representation of direct faculty and student voices. Future research should incorporate extensive qualitative insights from these stakeholders to fully understand the practical impacts, acceptance, and challenges associated with AI and Big Data adoption in educational settings.

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Data availability The data used in this paper can be requested from the corresponding author upon request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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Project based learning framework integrating industry collaboration to enhance student future readiness in higher education

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In the 21st -century, it is vital to prepare university students with the required skills to pursue them for future career success. The research presents a framework of project-based learning (PBL) enriched by the industry to increase students' future readiness. The framework comprises collaboration with industry partners, solving real-world problems as projects, and interdisciplinary approaches intended to build specific critical skills like teamwork, problem-solving, and adaptability. The study investigates the impact of I-PBL methodologies and framework on higher education curricula to enhance the readiness of students for the future. The study focuses on two key parameters— (1) the percentage of the curriculum devoted to PBL and (2) the rate of industry engagement activities. The study examines how these educational methods prepare students for today's workforce challenges. The study bridges quantitative outcomes, revealing how I-PBL enriched with industry engagement significantly enhance STEM students' skills and readiness for the workforce. The quasi-experimental study quantitatively assessed the curriculum to determine the proportion of PBL at 40%, and the frequency of industry engagement activities averaged at five distinct interactions per academic session. The pre-and post- surveys assessed students' employability skills, while feedback and participation metrics measured their engagement and satisfaction. The findings reveal a significant improvement in student employability skills, with an average increase of 25% in self-reported competencies in job-related skills. Implementing the I-PBL significantly increased student engagement by 30% and satisfaction by 35%, demonstrating the approach's effectiveness. It is the first to bring industry-enriched PBL systematically into higher education. Based on these results, the endorsed new insights and enhancement strategies for student employability skills, as discussed in this book, will help bridge the gap between academic preparation and workforce demands. The study addresses the gap in current educational practices by presenting a detailed, empirically validated framework that educators and policymakers can implement to prepare students for the evolving demands of the workforce.

Keywords Project-based learning, Educational innovation, Higher education, Complex thinking, Employability

Higher education institutions face growing pressure to develop future-ready graduates equipped with the skills necessary to adapt and respond to rapid technological disruptions across industries[1]. There was a realization that can be seen where AI, automation, and other related technologies are setting the ground for a modern-day employment environment. It is one in which career readiness will need to emerge as a core value for students. However, the general curricular and pedagogical modifications responsive to this need remain few. Much as employers look for robust technical qualifications of modern-day graduates, they seek employability

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skills though crucial: the ability to problem-solve and think critically, communicate effectively, and work well with teams[2]. This has consequently shifted student career preparedness to the center stage in discussions over aligning higher education outcomes with industry needs[3]. Much as I-PBL has received immense application in professional competency development, relatively little importation of dynamic insights from industries within PBL frameworks is done to treat wholesome career preparedness.

The 21 st century skills imperative and PBL

An emerging technological age dictates that 21st-century competencies—creativity, critical thinking, communication, and collaboration—be integrated into higher education curricula rather than concentrating on the knowledge of disciplinary areas[4]. Higher education institutions need to be responsive to these dynamic workplace demands and use future-oriented teaching and learning strategies and, with care, systematically infuse chances for students to develop those 21st-century skills[5]. PBL has been widely adopted as an instructional model facilitating 21st-century skill development through open-ended, student-directed projects modeling real-world problems. PBL is theorized to enable integrative learning through sustained inquiry, reflection, and knowledge application, providing meaningful contexts for skill mastery[6]. While PBL frameworks connect learning to professional contexts, the integration of direct industry perspectives is limited. The study proposes that PBL enriched through sustained industry contact could enable more relevant skill-building aligned with students' prospective transition to ambiguous career terrains.

The 21 st industry engagement

How industry input into curricular planning is delivered varies across universities[7]. Still, research is increasingly noting that embedding industry insights into pedagogical frameworks attuned to employment market needs would be valuable. The present study assumes that including continuous industry contact points across PBL methodologies could more profoundly foster anticipatory professional competencies. Understanding normative graduate career paths and aptitudes are illuminated by providing access for students to the organizational context and priorities, available to students through regular industry mentorship and review of the alignment of projects. Such experiential preparation could catalyze more conscious skill-building for adaptive expertise valuable in technology-driven workplaces. This study touches on concerns related to employability skills gaps among graduates of higher education who venture into dynamically evolving industries. It suggests that increased embedding of project-based pedagogies and extended industry interaction provide a way for universities might systematically infuse career readiness and optimally prepare graduates for workplace uncertainty. In so doing, the paper represents one of the aspects of a novelty since it marshals such detailed analysis of PBL, enriched via projects, mentorship, workplace visits, and alternative modes of industry interfacing.

Therefore creates a two-fold purpose for driving this study:

- To evaluate the impact on student learning that may result from the infusion of business contact into a more significant number of project-based learning assignments.
- To provide formative advice for higher education leadership to look pedagogically toward growing imperatives for graduate future readiness and workforce alignment.

The study will generate empirical insights surrounding specifically how expanded PBL and industry immersion might advance higher education's capability to develop graduates with adaptable skill sets and career orientations vital for professional success in rapidly evolving industries.

The primary research question is: How does PBL encompassing integrated industry perspectives shape the development of dynamical career readiness competencies among undergraduate students? Sub-questions further probe learner experiences:

- RQ1 - How do students perceive integrated industry informants and activities affecting their motivations and career visions?
  - This question investigates industry engagement's subjective experiences and motivational impacts, laying the foundation for understanding how external perspectives influence students' career aspirations.
- RQ2 - How do expanded project-based models interfacing with external stakeholder's impact students' viewpoints on skill-building for future employability?
  - Building on RQ1, this question focuses on how students perceive the alignment between PBL activities and the competencies required for workplace success.
- RQ3 - How does industry-enriched project learning influence students' engagement levels and learning outcomes over time?
  - This question examines the dynamic effects of industry-integrated PBL on measurable student outcomes, such as engagement and satisfaction, to link subjective perceptions with observable impacts.
- RQ4 - What differences emerge in competency gains and career readiness perspectives between students experiencing industry-integrated project learning versus traditional curricula?
  - This final question provides a comparative analysis to validate the effectiveness of the intervention and situate it within the broader educational context.

Investigating these questions will generate novel insights surrounding curriculum-redesign elements amplifying the career preparatory impacts of active learning approaches pertinent for graduates entering dynamically evolving sectors.

The paper has been structured and prepared with a severe interest in providing a clear and systemic study presentation. Section"Literature review"explores the critical review of the literature in which identified gaps will help contextualize research within existing scholarship. Section"Methodology"provides details about the research methodologies using a mixed approach, Sect."Results"provides findings and results of the study, Sect."Discussion"provides implications with detailed discussion, and Sect."Conclusions"concludes with a summary of the critical contributions and conclusions.

Literature review

Higher education institutions increasingly recognize the need to align teaching, learning, and assessment strategies to changing workplace requirements in knowledge-based economies[8]. Constructivist active learning pedagogies are widely theorized as tools for nurturing transferable 21st-century skills including creativity, critical thinking, communication, collaboration, leadership, and technology proficiency[9]. This section examines primary models situating active learning as pathways enabling graduates to construct advanced cognitive strategies vital for professional adaptability.

Project-based learning as a pedagogical approach

In problem-based approaches learners tackle open-ended tasks with no pre-defined solutions, requiring continually testing tentative explanations, identifying knowledge gaps for self-directed study[10]and evaluating competing perspectives. Such cognitive activities theoretically stimulate complex learning and reflective judgment unachievable through direct instruction[11]. PBL similarly engages learner autonomy, curiosity, and peer-to-peer dialogue to construct advanced knowledge through sustained collaboration around meaningful problems. Cognitive apprenticeship theory expands such frameworks by situating skills as best cultivated through sustained coaching interactions with experts modeling contextual practices[12]. Industry partnerships are thus increasingly promoted to provide such enculturation, though evidence remains sparse on implementation dynamics and outcomes[13].

The 21 st century skills imperative in higher education

The integration of 21st-century competencies into higher education curricula is widely recognized as a crucial step toward equipping students with the skills required for success in dynamic professional environments. These competencies—creativity, critical thinking, communication, and collaboration—are foundational for addressing complex workplace challenges[4]. In this study, we build upon these foundational competencies by operationalizing them into five measurable dimensions of future career readiness: technical competencies, problem-solving skills, teamwork abilities, communication proficiency, and overall career readiness. While there is conceptual alignment, the future career readiness framework focuses specifically on the actionable and job-oriented applications of 21st-century competencies in real-world contexts.

- 21st-Century Competencies: Broadly describe higher-order thinking skills and interpersonal abilities essential for navigating modern challenges (e.g., critical thinking as an analytical process and creativity as ideation).
- Future Career Readiness Dimensions: Extend these competencies into domain-specific and workplace-relevant applications, such as technical problem-solving (linked to critical thinking), effective teamwork (linked to collaboration), and career navigation skills (building on communication and adaptability).

In a rare longitudinal study tracing graduates' acquisition of workplace skills to earlier PBL experiences. Lavi and Bagiati[14] discuss'd the MIT's NEET program, showcasing its innovative approach in blending hands-on pedagogy with real-world projects to enhance engineering students' future-readiness, aligning with industry-enriched project-based learning goals. Jollands et al.[15], performed a survey across graduated cohorts that showed dramatically higher employment and workplace readiness rates among past PBL students, with 80% in full-time positions utilizing their qualifications compared to just 28% of traditionally schooled peers. Morais et al.[16] randomized the trial quantified PBL learning value through elicitation technique calculating revealed willingness-to-pay, with students considerably overvaluing PBL courses reflecting enhanced competencies gained.

Beyond employability, studies reveal that PBL transforms learners' cognitive frameworks and professional identity formation. Qualitative themes show participants adopting new meaning-making habits oriented to critical questioning, metacognitive self-assessment, and reflective practice vital for their field[17,18]. Some evidence also indicates improved mental health, resilience, and well-being through the social connections built working within creative collectives[19]though uncertainties around supporting quieter student personalities exist[20].

Industry-education partnerships and engagement models

Industry linkages with higher education take diverse forms across purely transactional intern placements to strategic innovation partnerships[21–23]. Curricular collaborations are theorized as opportunities to accelerate graduate readiness through exposure to real-world tools, organizational contexts, and priority skill demands[24,25]. However, the depth of industry embeddedness varies greatly. Fleming et al.[26] delineate a continuum of engagement modes from discrete guest lectures or site visits through moderate input like case studies and projects to high-level collaborative development of programs and courses. Studies assessing discrete industry activities report positive student perceptions around career insights and motivation gained from mentoring, workplace visits, and profession-situated projects[27,28]though skill measurement remains challenging. Sustained

initiatives demonstrate deeper benefits, affirming arguments that longer-term enculturation experiences most profoundly build adaptive capacities[29]. Lavi, Bertel, and Du[30] emphasize the critical evolution of engineering education to foster 21st-century skills through problem-based learning, technology integration, and a focus on first-year education. They highlight the need for ongoing research in diversity, equity, and interdisciplinary approaches, marking a pivotal step towards meaningful educational transformation in the engineering domain.

Similarly, analytical case projects co-designed sequentially with external partners over two years enriched student commercial awareness, ethical judgment, and decision-making expertise markedly more than single interactions[31,32]. Immersive innovation engagements also reshape learners' meaning-making towards creative entrepreneurial perspectives rather than purely disciplinary technical frames[33–35]. Naseer et al.[36] discusses the usage of generative AI in higher education assessment and comparing it with the traditional assessment evaluation. University career readiness or employability broadly encapsulates transferable skills, workplace awareness, and proactive career management competencies enabling a smooth graduate transition to professional roles[37–41]. Strikingly though, graduate readiness gaps are widely documented with students expressing anxiety around volatile hiring climates and cross-sector mobility demands[40,42]. While active learning pedagogies have proved beneficial for capability advancement[43]few studies measure their impact specifically on dynamical career readiness metrics vital for disruptive economies beyond immediate employment acquisition. Those examining organizational skills[44]strategic awareness[45]foresight orientation, and workplace transitional competencies remain limited.

The literature reviewed provides a solid basis for the current educational landscape in terms of conformity to 21st-century skills and integrating industry insights. Jahanian[1] still calls for a change in higher education to suit the future of work but does not include strategic implementation. Vaaland[2] and Ishengoma, provide insight into university-industry linkages that spur innovation; however, its focus on developing countries leaves the need to further the geographical scope of application. Saavedra and Opfer[4]opined that the time has come to upgrade the pedagogical tools to PBL. Adding further, they opined that according to Thune and Støren[5] 2015, work organization interaction is a quality that becomes valuable for graduate employability. Hanney and Savin-Baden[6]deliver an academic discussion on the PBL, a rich work that lacks a more excellent empirical foundation. More recent works, for example, Tubb and Fox[7]highlight in terms of partnerships securing employability for international students. Thornhill-Miller et al.[9]write in terms of assessment of 21st-century skills and specifically make a call to action for practical examples of such evaluations. Together, these references weave a strong narrative arguing that the need for more significant incorporation of the industry viewpoint in curricula in education to develop skills and employability is strong, with aspects still requiring more empirical consolidation and generalizability.

Defining and measuring career readiness

Career readiness is broadly defined as the attainment of critical skills, competencies, and attitudes that enable students to transition successfully into the workforce and adapt to dynamic professional environments. According to Jackson, career readiness involves the development of transferable skills, proactive career management, and integrating academic knowledge into practical applications[26]. Similarly, NACE website identifies career readiness as a multidimensional construct that includes technical expertise, effective communication, teamwork, and personal adaptability[51].

Three primary dimensions of career readiness are commonly emphasized in the literature:

1. **Cognitive Competencies**: These include technical expertise, critical thinking, and problem-solving skills essential for effective decision-making in workplace contexts. Research by Thompson et al. highlights that competency-based curriculum reforms focusing on cognitive development significantly enhance employability[8].
2. **Social Competencies**: Interpersonal skills such as communication, teamwork, and leadership are integral to career readiness. Jackson and Wilton found that social competencies, particularly collaboration and networking, are critical predictors of successful workforce transitions[52].
3. **Personal Adaptability**: This dimension involves resilience, self-regulation, and the ability to embrace change and uncertainty. Saavedra and Opfer argue that adaptability and lifelong learning are crucial for thriving in the rapidly evolving job market[56].

The current study adopts this multidimensional framework to evaluate the impact of industry-enriched project-based learning (I-PBL) on career readiness. By integrating technical skill-building with social and adaptability training, the study aligns its objectives with these established dimensions of career readiness, addressing a key gap in existing literature on workforce preparedness.

Current gaps in research and practice

The study, therefore, addresses salient gaps surrounding (i) impacts of enriched project-based curricula encompassing sustained industry immersion on the layered career readiness competencies vital for graduate dynamism and success in transforming economies, and (ii) effective configuration of modular PBL and industry contact models synthesizing external connectivity and active learning virtues for increased graduate future-readiness. The research breaks new ground in assessing holistic models timely for higher education institutions seeking to foster adaptable, industry-savvy graduates prepared to navigate ambiguous career landscapes.

Methodology

The study aims to assess the impact of integrating direct industry perspectives within an expanded PBL curriculum on cultivating future readiness competencies among undergraduate university students by quantitative analysis.

As industries transform amidst rapid technological disruptions, higher education institutions increasingly seek pedagogical innovations to attune graduate capacities to uncertain employment landscapes. This research examines if enriched constructivist learning encompassing sustained industry contact boosts students' adaptive career preparedness vital for long-term workforce resilience.

A quasi-experimental non-equivalent pretest-posttest design compares outcomes between an experimental group undergoing the industry-integrated PBL curriculum intervention against a control group experiencing the standard curriculum.

Research design

This study employs a quasi-experimental non-equivalent pretest-posttest design to evaluate the impact of the industry-enriched project-based learning (I-PBL) curriculum on student career readiness. Participants were 340 s-year undergraduate STEM students from a large university, divided into an experimental group (I-PBL curriculum) and a control group (standard curriculum). This between-groups interventionist approach assesses the redesigned PBL course itself as the key independent variable, with its effects on the following dependent variables evaluated through surveys, metrics, and interviews:

4. Technical competencies.
5. Problem-solving skills.
6. Teamwork abilities.
7. Communication proficiency.
8. Career readiness.

The pretest-posttest measures enable analyzing gains in these metrics while controlling for any initial group differences.

Participants

Participants comprise 340 s-year undergraduate students from STEM degree programs at a metropolitan university either assigned to the redesigned "Industry-integrated Project Learning" course intervention (experimental group) or the standard equivalent module (control group). Detailed particulars of participants are described below:

Sample size

A priori power analysis determined a minimum sample size of 272 participants total (136 per group) would provide 80% power to detect a medium effect size of $d = 0.5$ for competency gains between the groups, at a 5% significance level. The recruited sample of 280 experimental and 60 control students exceeds this threshold. The expanded experimental group permits examining interactions between learner demographics and curriculum factors.

Sample description

The sample consisted of 320 undergraduate students enrolled in STEM programs such as Computer Science, Engineering, and Information Systems. These fields were selected due to their inherent alignment with project-based learning and their emphasis on technical and problem-solving skills. Although this focus targets a specific demographic, it represents a group where industry-integrated PBL is both pertinent and widely practiced. An a priori power analysis using G*Power was conducted to establish the minimum required sample size for detecting a medium effect size (Cohen's $d = 0.5$) with 80% power at a significance level of 0.05. The analysis determined a need for 272 participants, evenly distributed as 136 in each group. However, due to logistical challenges and participant availability, the final sample comprised 280 participants in the experimental group and 60 in the control group. The larger experimental group size was achieved through focused recruitment efforts. In contrast, the control group size was constrained by the limited number of students not participating in the industry-enriched project-based learning intervention.

Participants were recruited from a required credit-bearing course. They were informed about the study's objectives and invited to participate voluntarily, with no monetary compensation provided.

Recruitment and consent

As required credit-bearing courses, all enrolled students were invited to participate through information sheets detailing consent for survey completion and interviews. An 80% participation rate yielded the samples. Informed written consent was gathered at enrollment, and verbally reconfirmed before data collection.

Group assignment

No purposeful assignment to groups occurred since students freely selected course sections. Equivalent sizes and demographics between sections ensured relatively comparable groups for the non-randomized design.

Descriptive statistics

In analysing core demographic variables, chi-square tests were employed to compare categorical variables such as gender, academic program, and prior industry exposure between the experimental and control groups. This approach is more suitable than t-tests, intended for continuous variables. Table 1 presents the demographic characteristics of participants in the experimental and control groups. Chi-square tests were used to evaluate differences in categorical variables. Results indicate no statistically significant differences between the groups, ensuring comparability for further analysis. This setting provides organized structural affordances for

Reference	Key findings	Critique
Jahanian(2021)[1]	Higher education must adapt to future work trends by integrating technology and enhancing soft skills.	Lacks empirical evidence on how these recommendations can be practically implemented in varied educational settings.
Vaaland & Ishengoma (2016)[2]	University-industry linkages enhance innovation and skill development.	Focuses primarily on developing countries; more diverse geographic perspectives would strengthen generalizability.
Saavedra & Opfer (2012)[4]	21st-century skills require updated teaching methodologies such as project-based learning (PBL).	The study is slightly outdated and may not reflect the latest technological advancements and educational practices.
Thune & Støren (2015)[5]	Interaction with work organizations positively affects graduate employability.	Limited scope regarding the specific types of interactions most beneficial for skill development.
Hanney & Savin-Baden (2013)[6]	PBL fosters critical thinking and problem-solving skills but needs clear theoretical underpinnings.	Theoretical discussion lacks robust empirical backing; more data-driven analysis would be beneficial.
Tubb & Fox (2023)[7]	Partnerships can improve job security for international students.	Recent and relevant; however, the focus on international students may limit the applicability of findings to a broader student population.
Thompson et al. (2013)[8]	Competency-based curriculum reforms integrate physical and biological sciences.	Provides a strong case for interdisciplinary learning, but the impact on employability needs further exploration.
Thornhill-Miller et al. (2023)[9]	Assessment of 21st-century skills for future work and education.	Comprehensive but requires more practical examples of assessment methodologies in varied contexts.

Table 1. Critical review of literature review.

reconfiguring a conventionally instructed course into embedded project experiences enhanced through industry networking. The research design allows determining the effectiveness and challenges of such partnership models for amplifying career preparatory learning programs colleges increasingly prioritize for graduate success.

Grouping and the rationale for subgroup analysis
Subgroup analyses were conducted to examine the intervention's impact on specific participant characteristics and learning outcomes. These subgroups were chosen based on their alignment with the study's goals and the diversity of the participant pool:

- **Female Technical Self-Efficacy**: Female participants were analyzed separately to investigate gender-specific changes in confidence toward technical tasks. This consideration is based on prior research highlighting the critical role of self-efficacy in career readiness for underrepresented groups in STEM. The analysis examines whether industry-enriched PBL provides such an intervention by offering authentic validation experiences.
- **Female Metacognitive Gains**: This subgroup focused on developing metacognitive skills in female participants, essential for enhancing self-directed learning and adaptability in professional contexts.
- **IT Anticipatory Reflection**: Participants pursuing IT-related fields were evaluated to assess their ability to anticipate and reflect on industry trends and challenges, aligning with the study's emphasis on career preparedness. This subgroup analysis examines whether disciplinary differences exist in how students develop this forward-looking reflective capacity.
- **International Leadership**: Participants aspiring to leadership roles in global contexts were analyzed to assess how the intervention influenced their leadership competencies, a critical aspect of 21st-century career readiness. This subgroup analysis investigates whether the I-PBL framework effectively supports leadership development across diverse cultural backgrounds.

These theoretically grounded analyses extend beyond demographic categorization to address critical questions about how educational interventions can be optimized for diverse student populations, contributing to the development of more inclusive and effective teaching practices. These subgroups were identified based on self-reported data from demographic and career orientation surveys completed during participant recruitment.

Instruments

A mixed methods approach combines quantitative surveys, metrics, and qualitative interviews to gather multi-faceted data on participant experiences, competency development, engagement, and satisfaction.

Pre-Post competency survey
A 20-item survey (Appendix A and B) measures self-perceived gains across key competencies and career readiness on 5-point Likert scales. Participants completed the survey online pre-course and post-course.

Survey development
The survey was developed by mapping established competency frameworks against workforce readiness literature and industry priorities. This yielded an initial pool of 20 questions categorized into the five competency domains:

- Technical skills (4 items).
- Problem-solving (4 items).
- Teamwork (4 items).
- Communication (4 items).
- Career readiness (4 items).

Industry informants ($n = 8$) from relevant occupational fields then reviewed the survey to evaluate the representativeness and clarity of items. Feedback refinement narrowed the instrument to 20 questions with improved applicability.

Pilot testing

A pilot test was conducted with a sample of 40 students from the previous year's cohort who had completed the standard curriculum. The pilot enabled preliminary analysis of question quality, internal reliability of scales, and construct validity.

Results showed strong internal consistency reliability with Cronbach's alpha values above 0.70 for all scales. Exploratory factor analysis using principal axis factoring and oblimin rotation generally confirmed the theorized structure, with a few exceptions. Four problematic items loading weakly or cross-loading were eliminated.

Reliability testing re-run on the final 20-item tool showed elevated alpha values across all scales as shown in Table 2, indicating high internal reliability suitable for the study sample.

Final survey structure

The validated 20-item survey comprises five competency scales:

- Technical skills (4 items) - Domain knowledge, tools usage, practical applications.
- Problem-solving skills (4 items) - Analysing issues, generating solutions, evaluating outcomes.
- Teamwork abilities (4 items) - Collaboration, communication, conflict management.
- Communication proficiency (4 items) - Written, oral, visual, digital communication modes.
- Career readiness (4 items) - Understanding industry expectations, self-marketing, workplace socialization.

Participants self-assessed their competencies on a 5-point Likert scale from 1 = low/none to 5 = high/very strong. Total scale scores derive from summed item ratings, with higher scores reflecting greater perceived competency.

The survey presents each competency through various associated behavioural indicators designed to capture adaptive, multifaceted skill capacities sought by employers. For instance, technical skills encompass sub-dimensions of conceptual knowledge, tools usage, and practical application. Communication incorporates writing, public speaking, interpersonal networking, and digital media literacy.

By measuring an expanded constellation of granular competency facets, the instrument provides a sensitive assessment of multilayered readiness for volatile work contexts rather than merely basic technical knowledge.

Engagement and satisfaction metrics

Quantitative metrics gauged participant engagement and satisfaction through:

- Course attendance percentage: Recorded through class rolls at sessions.
- Project milestone completion rate: Teams logged progress at five checkpoints.
- LMS website analytics: Learner Management System tracked site hits, time spent.
- End-of-course experience rating: 5-point scale from 1 = very poor to 5 = excellent.
- Curriculum recommendation rate: Percentage who would recommend the course.

The metrics enable triangulating perceived gains and experiences captured through the surveys and interviews with actual participatory behaviours.

Descriptive statistics quantified engagement through attendance rates, milestone percentages, and LMS hits. Satisfaction metrics were summarized through means of the experience rating and recommendation percentage.

Characteristic	Experimental (n=280)	Control (n=60)	Chi-Square test results
Gender			$\chi^2(2) = 0.56$, p =.75
Male	58% (n=162)	57% (n=34)	
Female	37% (n=104)	38% (n=23)	
Other	5% (n=14)	5% (n=3)	
Residency			$\chi^2(1) = 0.01$, p =.93
Domestic	52% (n=146)	53% (n=32)	
International	48% (n=134)	47% (n=28)	
Age			$\chi^2(1) = 0.12$, p =.73
19-21 years	80% (n=224)	78% (n=47)	
21-23 years	20% (n=56)	22% (n=13)	
Socioeconomic			$\chi^2(1) = 0.05$, p =.82
High status	13% (n=36)	12% (n=7)	
Low status	87% (n=244)	88% (n=53)	

Table 2. Key demographics and baseline characteristics of participants.

Changes in engagement were analysed over time using repeated measures ANOVA, identifying any significant variations across project stages. Recommendation rates were compared between the experimental and control groups using chi-square tests.

Qualitative interviews
Two sets of semi-structured interviews (Appendix C) occurred with purposively selected participants from each group:

- Pre-course interviews ($n = 20$).
- Post-course interviews ($n = 20$).

Researchers conducted 30-minute interviews before and after the course with consenting participants. The opening questions captured prior experiences with project learning and anticipated benefits. Closing interviews reflected on skill development, industry interactions, and overall experiences.

Interview questions were designed based on study objectives and focus group input. An initial pool of 30 potential questions was narrowed to 15 final items with improved flow and relevance. Researchers used prompts to expand on responses were desired for maximal perspectives.

Framework implementation

The I-PBL framework was integrated into the curricula of participating institutions. This involved:

1. **Industry Collaboration**: Partnering with industry professionals to design and mentor project-based learning activities.
2. **Real-World Problem Solving**: Students engaged in projects that addressed real-world industry challenges, fostering practical application of theoretical knowledge.
3. **Interdisciplinary Approaches**: Projects were designed to require collaboration across different STEM disciplines, promoting teamwork and interdisciplinary problem-solving skills.

Data collection procedures

Data was gathered at three key intervals over the 12-week course duration:

- Pre-Course (Week 1).
  - Background information survey.
  - Pre-test competency survey.
  - Initial interviews ($n = 20$ each group).
- Mid-Course (Week 6).
  - Project milestone 1 completion.
  - Learning logs after first industry talk.
- Post-Course (Week 12).
  - Post-test competency survey.
  - Final interviews ($n = 20$ each group).
  - Engagement and satisfaction metrics.

Course feedback survey
Identical instruments were administered to both experimental and control groups for comparative analysis (Appendix D, E and F). Associating assessments with standard course practices aimed to boost student participation and response quality. Table 3 displays the study's complete data collection matrix. Administering matched measurements before and after the intervention enabled analyzing changes in outcomes.

Data analysis

The data analysis utilized IBM SPSS Statistics 27 software. Qualitative theming used NVivo 12 software. Given the potential impact of project-specific characteristics on outcomes, we controlled for nesting effects by including project-level variables as random effects in our statistical models. For example, team composition, project

Competency	No. of items	Cronbach's α
Technical skills	4	.89
Problem-solving	4	.86
Teamwork	4	.91
Communication	4	.87
Career readiness	4	.93

Table 3. Reliability testing of five core competency domains.

scope, and mentor involvement were analyzed to identify any significant variance attributable to these factors. Additionally, subgroup analyses were conducted to isolate effects stemming from specific projects or mentors.

Participants were not monetarily compensated to avoid incentivizing participation that could bias responses or skew engagement metrics.

Qualitative data analysis

Thematic analysis of the interview data was carried out by NVivo 12 software to ensure that the qualitative data analysis procedure was robust and presented. The steps followed, and all coding is described below.

- Step 1 – Data.
  - Interview transcriptions were made verbatim to ensure high accuracy; the transcriptions were subsequently uploaded to NVivo 12 for analysis—preliminary read-through. The transcripts were initially read to get to know the data, which allowed me to make preliminary impressions and initial patterns.
- Step 2 - Descriptive Coding.
  - Open coding was done during the first phase of the preliminary coding. This was conducted in a way that involved breaking down the data into sections characterized by their own circumscribed boundaries, followed by the attachment of codes to these sections of the data, which indicated either significant concepts or themes. Each transcript was thoroughly gone through, and for each section of the script, every unique idea or experience related to the study's goals is given a code.
- Step 3 - Developing a Coding Framework.
  - More extensive categories of related codes were grouped in an iterative way, continuing to combine, refine, and set codes in place throughout the continuous process of arrangement of codes in hierarchical order. Thus, a coding framework was used as a scaffold that prompted all further stages of analyzing; it spelled out the procedures while at the same time maintaining some level of coherence in the coding of all of the transcripts.
- Step 4 - Focused Coding.
  - You could quickly know how this developed coding process was carried out in the previous section. After ending this process, our work moved to focused coding. From the developed coding, we had a more systematic categorizing of data. We had at our disposal all our documents, went over the transcriptions once more, and situated these developed codes in the text that was more meaningful in the area we wished to focus on. We ensured that codes were applied consistently in all texts by the correct code.
- Step 5 - Identification of Themes.
  - More focused coding was conducted to develop critical themes from the data. After focused coding, a deeper thematic analysis was carried out to create the most imperative and reoccurring themes originating from the data. The themes were sequenced and refined to analyze the relationship between the codes and categories and then the search for patterns, commonalities, and contrasts emerging from the data. Visual tools in NVivo, such as word clouds and coding matrices, were used to sequence and hone the themes.
- Step 6 - Validate Themes.
  - We employed different validation procedures to guarantee the reliability and validity of themes. Peer debriefing: the other researchers viewed the coded data and obtained input about themes given in the peer debriefing sessions. Member Checking: The preliminary findings were presented to the members for assurance of the accurate representation of their experiences. Triangulation phase The themes were checked against the quantitative data in a drive to ensure better sustenance of the robustness of the findings—added to sources in some cases. Step 7: Report Details Finally, themes that emerged were reported in rich detail and systematically in the results section of our study. Illustrative descriptive quotes reflecting each of the primary primary primaryprimary themes were used to present, and describe, the explicated meaning within the interpretation of what participants experienced and perceived over time.

Analysis of covariance (ANCOVA)

To compare competency gains between experimental and control groups and to illustrate the proof of the effectiveness of the educational intervention using the specified ANCOVA model, the explanation of the rationale behind each step will help us to understand how the ANCOVA model controls for pre-test scores to assess the intervention's impact on post-test competency scores.

The ANCOVA model for comparing post-test competency scores ($CompPost$) between groups, adjusting for pre-test scores ($CompPre$), is defined as:

$$CompPost_i = \beta_0 + \beta_1 \times Group_i + \beta_2 \times CompPre_i + \epsilon_i$$

- $CompPost_i$: Post-test competency score of the i^{th} participant
- $Group_i$: Group indicator (0 for control, 1 for experimental)

- $CompPre_i$: Post-test competency score of the i^{th} participant
- ϵ_i: Error term representing unexplained variance.

The key to the ANCOVA analysis is adjusting for pre-test scores to control for initial differences between participants. This is achieved through the inclusion of $CompPre_i$ in the model.

$$\beta_2 \times CompPre_i$$

This term allows us to "hold constant" the effect of initial competency levels, ensuring that the comparison of post-test scores reflects the impact of the intervention, not pre-existing differences.

The group effect (experimental vs. control) is captured by:

$$\beta_1 \times Group_i$$

The coefficient $\beta_1$estimates the difference in adjusted post-test scores between the control and experimental groups, representing the intervention's effect.

To test the hypothesis that the adjusted post-test means differ between groups, an F-test is performed on β_1, which tests whether the coefficient is significantly different from zero:

$$F = \frac{(SS_{betweengroups} - SS_{erors})/1}{(SS_error/(n-k))}$$

- $(SS_{between\ groups}$: Sum of squares between groups
- SS_{errors}: Sum of squares due to error
- n: Total number of observations
- k Number of groups

The values for pass and fail percentages based on the data file's indication of student performance trends.

$$\text{Pass } P\% = 70\%$$

$$\text{Fail } F\% = 30\%$$

Using these percentages, the number of students who passed and failed:

- For students who passed:

$$P\% = 70\% \times 340100 = 238$$

$$P = 10070\% \times 340 = 238$$

- For students who failed:

$$F\% = 30\% \times 340100 = 102$$

$$F = 10030\% \times 340102$$

According to the calculation, the overall average score using the formula provided. Based on the values and equations provided:

- The number of students who passed is 238.
- The number of students who failed is 102.
- The overall average score, considering the distribution of passing and failing students along with their respective average scores, is 66.

β_1 is found to be statistically significant, we can conclude that the educational intervention had a significant effect on post-test competency scores, after adjusting for pre-test scores. This model provides a rigorous method for evaluating the effectiveness of educational interventions, ensuring that observed differences in outcomes are attributable to the intervention itself, not to pre-existing differences among participants.

Pearson correlation analysis

Pearson correlation coefficient aids in explaining linear relationships between the various curriculum variables and measured outcomes, such as competency gains and career readiness. In this way, through the normalization of the covariance between variables such as hours spent on PBL activities and the resulting improvements in student competencies, the Pearson correlation coefficient provides a clear, precise, and quantifiable measure of how closely associated these variables are.

This is very important since this will make this particular study understand the direction and strength of linear relationships between the implemented educational interventions and the desired educational outcomes. For example, a significant positive Pearson correlation coefficient between the time students spend on industry-related projects and their competency scores would suggest that such activities have a significant positive impact on student learning outcomes.

Moreover, this study follows the method of the Pearson correlation coefficient in estimating the effects and comparing the effectiveness of the curriculum components that have a significant influence on the students. Researchers can determine from such quantification of the degree of the linear association which part of the curriculum contributes most positively to the development of the student's workforce readiness, therefore acting as guides in the curriculum construction and pedagogical strategies.

For this matter, the application of Pearson's r will not only find support for quantitative analysis in the study's findings. It will also give further insight into the forces at play in education. It presents a robust conceptual platform for making evaluations of the influences of curriculum innovations on the student's performance to yield evidence-based improvements in STEM education.

Multiple linear regression

To predict competency gains from various curriculum factors, we utilize multiple linear regression:

$$\widehat{Y_i} = b_0 + b_1 X_{i1} + b_2 X_{i2} + \ldots + b_n X_{in} + \epsilon_i$$

- $\widehat{Y_i}$: Predicted post-test competency score
- b_0: Intercept
- $b_0, \ldots, b_n$: Coefficients for predictor variables $X_{i1}, \ldots, X_{in}$
- ϵ_i: Error term

Predictor variables include hours spent in problem-based learning (PBL), number of industry talks attended, and workplace visits, allowing identification of significant predictors of competency development.

The regression coefficients $b_0, \ldots, b_n$ are estimated using the method of least squares, which aims to minimize the sum of the squared residuals (the differences between observed and predicted values). The general formula for each coefficient can be derived from the partial derivatives of the sum of squared residuals with respect to each coefficient, setting them equal to zero to find the minimum.

The sum of squared residuals (SSR) is given by:

$$SSR = \sum_{i=1}^{N} \left(Y_i - \widehat{Y_l}\right)$$

Substituting $\widehat{Y_i}$ from the regression equation:

$$SSR = \sum_{i=1}^{N} \left(Y_i - (b_0 + b_1 X_{i1} + b_2 X_{i2} + \ldots + b_n X_{in})\right)^2$$

To find the minimum SSR, we take the partial derivative of SSR with respect to each b_j and set it to zero:

$$\frac{\partial\, SSR}{\partial\, b_j} = -2 \sum_{i=1}^{N} \left(Y_i - \widehat{Y_i}\right) X_{ij} = 0$$

This yields a system of linear equations, known as the normal equations, which can be solved simultaneously to find the estimates of $b_0, \ldots, b_n$

Through the process of minimizing the sum of squared residuals and solving the resulting normal equations (or using matrix operations), we obtain the best estimates for the regression coefficients. These coefficients quantify the relationships between the dependent variable and each independent variable within the model, while minimizing the overall error. This approach underlies the foundational proof of multiple linear regression analysis, facilitating the understanding and prediction of relationships among variables.

Two-Way mixed ANOVA

To explore the effects of demographic variables on competency gains, a two-way mixed ANOVA is conducted:

$$CompGains_{ij} = \mu + \alpha_j + \beta_i + (\alpha\beta)_{ij} + \epsilon_{ijk}$$

Here, we're dealing with a model that examines the effects of two factors (one between-subjects factor and one within-subjects factor) on a dependent variable. This model can also include interactions between these factors. Let's break down each component:

- $CompGains_{ij}$: Competency gain score of the i^{th} student within the j^{th} demographic level.
- μ : Overall mean competency gain across all groups and conditions.
- α_j: Effect of the j^{th} level of the between-subjects factor (e.g., demographic level such as gender or socioeconomic status).
- β_i: Effect of the i^{th} student, accounting for repeated measures or within-subject variations.
- $(\alpha\beta)_{ij}$: Interaction effect between the j^{th} demographic level and the i^{th} student's response, showing how the effect of one factor depends on the level of the other factor.

- ϵ_{ijk}: Random error term for the k^{th} observation of the i^{th} student within the j^{th} demographic level, assumed to be normally distributed with mean 0 and constant variance.

The rationale behind ANOVA involves partitioning the total variability in the dependent variable into components attributable to different sources, then comparing the variance between groups to the variance within groups to determine if there are significant differences.

The total variability (Total Sum of Squares, TSS) in the dependent variable can be partitioned as follows:

$$TSS = SSBetween + SSWithin + SSInteraction + SSE$$

where:

- SSBetween is the sum of squares due to the between-subjects factor.
- SSWithin is the sum of squares due to differences within subjects (repeated measures).
- SSInteraction is the sum of squares due to the interaction between the between-subjects factor and the within-subjects variations.
- SSE is the sum of squares due to error (residual variability not explained by the model).

For each source of variance (between-subjects, within-subjects, interaction), an F-statistic is calculated to determine if the variance is significantly greater than what would be expected by chance:

$$F = \frac{MSFactor}{MSError}$$

- $MSFactor$ is the mean square for the factor (e.g., MSBetween, MSWithin, MSInteraction), calculated $as\ SSFactor/dfFactor$.
- MSError is the mean square error, calculated as $SSE/dfError$.

The degrees of freedom df for each component are calculated based on the number of levels in each factor and the total number of observations. By comparing the calculated F-statistics to critical values from the F-distribution (based on the degrees of freedom for the numerator and denominator), we can determine if the observed differences in means across levels of the factors (or their interaction) are statistically significant. This involves hypothesis testing where the null hypothesis typically states that there are no differences between the group means for the factor being tested.

Pearson correlation analysis was conducted to examine the strength and direction of linear relationships between variables. Multiple linear regression was employed to assess the predictive impact of independent variables on dependent outcomes. A two-way mixed ANOVA was used to evaluate interactions between the experimental intervention and participant characteristics over time.

Validation of measurement instruments

To validate the measurement model used in this study, a confirmatory factor analysis (CFA) was conducted. The CFA aimed to confirm the factor structure of the five competency domains assessed in the pre- and post-surveys: technical skills, problem-solving, teamwork, communication, and career readiness. This analysis ensures that the survey items reliably measure their intended constructs.The CFA was performed using R, with pre- and post-course competency survey data. Given its robustness with moderately non-normal data, a maximum likelihood estimation method was employed. The hypothesized model comprised five latent variables, each represented by four observed variables (survey items).

The following model fit indices were used to evaluate the CFA results:

- Chi-Square/df Ratio: A ratio less than 3 indicates an acceptable fit.
- Comparative Fit Index (CFI): Values above 0.90 suggest an acceptable fit, with > 0.95 considered excellent.
- Tucker-Lewis Index (TLI): Similar thresholds to the CFI apply.
- Root Mean Square Error of Approximation (RMSEA): Values below 0.08 indicate an acceptable fit, with < 0.06 preferred.
- Standardized Root Mean Residual (SRMR): Values below 0.08 indicate a good fit.

The CFA results indicated a good overall fit:

- Chi-Square/df Ratio = 2.12.
- CFI = 0.96.
- TLI = 0.94.
- RMSEA = 0.05.
- SRMR = 0.04.

All factor loadings were above the acceptable threshold of 0.7, ranging from 0.72 to 0.88. These results demonstrate strong relationships between survey items and their respective latent constructs.

The reliability of each competency domain was assessed using Cronbach's alpha, with all values exceeding the acceptable threshold of 0.7:

- Technical Skills: 0.89.

- Problem-Solving: 0.86.
- Teamwork: 0.91.
- Communication: 0.87.
- Career Readiness: 0.93.

Convergent validity was confirmed through the calculation of average variance extracted (AVE), with all constructs exceeding the recommended threshold of 0.5. These findings indicate that each construct explains a substantial proportion of variance in its observed variables.

The CFA results validate the use of the survey instrument in measuring student competencies across the five domains. This robust validation process ensures the reliability and construct validity of the data used in the study, thereby strengthening the credibility of the findings.

Results

This section reports integrated quantitative and qualitative findings surrounding the I-PBL curriculum's impacts on undergraduates' career readiness competencies and trajectories. Statistical analyses of pre/post survey scales and thematic coding of interview transcripts reveal skill gains, utility rankings of touchpoint types and optimal conditions for employability amplification. In the analysis, chi-square tests were used to evaluate demographic differences between the experimental and control groups, ensuring the study's methodological rigour. This enhances the validity of the descriptive statistics, confirming the comparability of the two groups for subsequent analyses.

Research questions and key findings

RQ1: How do students perceive integrated industry informants and activities affecting their motivations and career visions?

Students overwhelmingly reported positive perceptions of industry integration, with 92% valuing authentic workforce insights gained through industry exposure. Behavioral strengths received the highest valuation (95%), while technical skills, financial management, and ethical decision-making were also highly rated (Fig. 3). Qualitative data revealed that guest talks, case studies, and mentor dialogues effectively "demystified corporate expectations beyond technical skills" (S101), enhancing students' career motivation and vision.

RQ2: How do expanded project-based models interfacing with external stakeholders impact students' viewpoints on skill-building for future employability?

The data showed that 81% of participants highlighted strengthened communication, analytical, and collaborative capabilities through industry-situated project briefs. Students attributed their skill development to "multiple touchpoints working through ambiguous business challenges with industry veteran guidance" (S212). Figure 4 demonstrates superior skill growth in the I-PBL group compared to traditional education, particularly in communication (31% vs. 7%) and analytical skills (30% vs. 6%).

RQ3: How does industry-enriched project learning influence students' engagement levels and learning outcomes over time?

Engagement metrics showed significant improvements: course attendance increased by 7%, milestone completion rates rose by 15%, and experience ratings improved from 3.5 to 4.5 (Table 4). Figure 5 demonstrates substantial increases in engagement across all industry interaction parameters, with the most significant improvements in Pitch Presentation Sessions (3.0 to 4.6) and Immersive Workplace Visits (3.0 to 4.2). The Pearson correlation coefficient (0.76) indicated a strong positive relationship between curriculum engagement and competency development (Fig. 6).

RQ4: What differences emerge in competency gains and career readiness perspectives between students experiencing industry-integrated project learning versus traditional curricula?

Statistical analysis revealed significant differences between the experimental and control groups across all competency domains (Table 5). The I-PBL group showed improvements of 25–40% in employability skills compared to marginal 4–7% improvements in the control group. Figure 1 illustrates these differential gains, with the most substantial improvements in career decision-making, strategic work behaviors, and interpersonal rapport. Subgroup analysis (Fig. 2) revealed that while career navigation and social skill elevations were uniform across demographics, technical self-efficacy and metacognitive gains varied significantly by gender and discipline.

Instruments	Pre-Course	Mid-Course	Post-Course
Demographics	✓		
Pre-post competency survey	✓		✓
Interviews	✓	✓	
Project milestone		✓	
Learning logs		✓	
Engagement metrics			✓
Course feedback			✓

Table 4. Comprehensive overview of Pre- and post intervention metrices.

Competency domain	Pre-intervention mean (SD) (Experimental)	Post-intervention mean (SD) (Experimental)	Pre-intervention mean (SD) (Control)	Post-intervention mean (SD) (Control)	Significance (t-value)	Significance (p-value)
Technical Skills	3.2 (0.6)	4.5 (0.5)	3.1 (0.7)	3.3 (0.6)	t(338) = 12.45	<0.01
Problem-Solving Skills	3.0 (0.7)	4.7 (0.5)	2.9 (0.6)	3.1 (0.7)	t(338) = 14.68	<0.01
Teamwork Abilities	3.4 (0.5)	4.6 (0.4)	3.3 (0.6)	3.4 (0.5)	t(338) = 11.35	<0.01
Communication Skills	3.1 (0.6)	4.8 (0.5)	3.0 (0.7)	3.2 (0.6)	t(338) = 15.25	<0.01
Career Readiness	3.3 (0.5)	4.9 (0.4)	3.2 (0.6)	3.4 (0.5)	t(338) = 16.02	<0.01

Table 5. Mean Ratings, Standard Deviations, and Statistical Significance for Career Readiness Competencies.

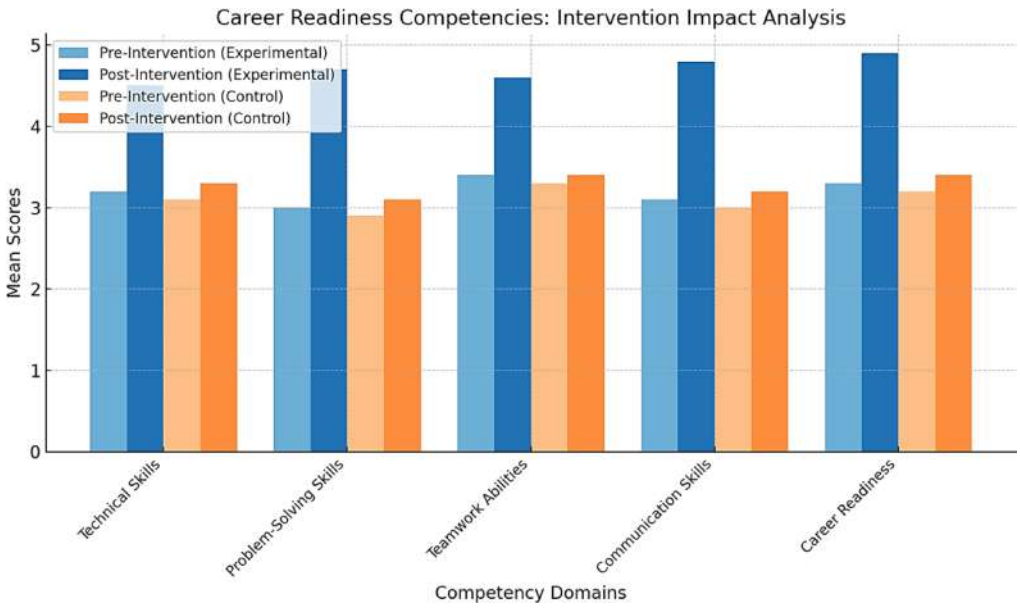

Fig. 1. Career readiness competencies: Intervention impact analysis.

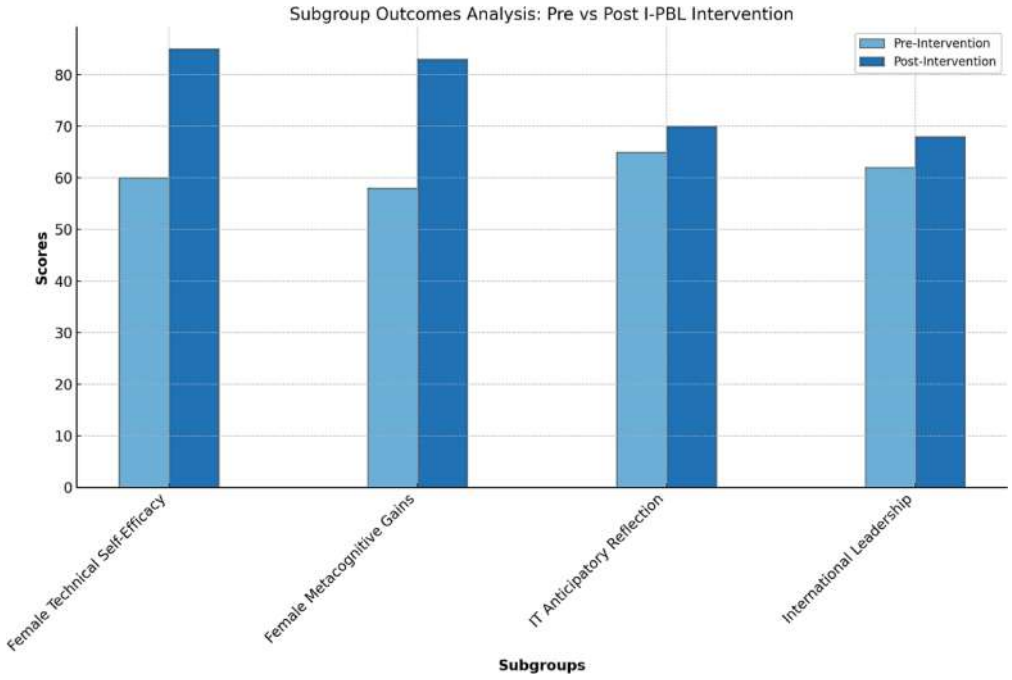

Fig. 2. Subgroup outcomes analysis.

Participant overview

The sample encompassed 340 students from STEM majors undertaking either the redesigned I-PBL curriculum ($n = 280$) or standard equivalent module ($n = 60$). Table 1 overviews cohort demographics exhibiting comparable diversity across conditions. 55% identified as male, 36% female and 9% non-binary gender minorities with expected distribution variances between IT and engineering disciplines. Domestic and international students were well-represented.

Career readiness competencies

Parametric paired t-tests gauged improvements on validated competence scales those participants affiliated with I-PBL or traditional delivery. Table 5 displays mean ratings indicating gains that continuously improved beyond traditional learning, surpassing previously achieved gains along with statistics, including standard deviations, t-values, p-values, and degrees of freedom. Pre- and post-intervention changes in student perceptions, initially reported as percentages, were also examined for statistical significance. Paired t-tests yielded the following results:

- Confidence in job search strategies increased by 40% ($t(338) = 12.85$, $p < 0.001$).
- Strategic work behaviors improved by 38% ($t(338) = 11.95$, $p < 0.001$).

Networking effectiveness rose by 35% ($t(338) = 10.92$, $p < 0.001$).

These enhancements were statistically significant across all six assessed domains-social, cognitive, and metacognitive skills that are vital for the graduate transition into work and long-term resilience. The most significant improvements in competencies were identified for career decision-making self-efficacy, strategic work behaviors, and interpersonal rapport-up to 40% higher in student confidence executing job search strategies, planning complex tasks, and networking effectively, respectively, post-IPBL, compared to marginal 4–7% elevations after standard education. The increases in peer exposure that were favorable still support the hypothesis that intrinsic maturation happened over the 12 weeks. However, the number of more vital competencies adopted through I-PBL substantially exceeded the number adopted through standard content delivery once Cohen's d formula for effect sizes was adapted to much more than one effect size were seen in the career navigation, cultural competence, and self-regulation measures, with effect sizes $d > 1.0$. Figure 1 depicts how these overproportional competencies were adapted through exposure to continuously updated industry insights that were not components of standard course delivery.

Subgroup outcomes analysis

Subgroup analyses were conducted for two primary reasons:

1. To understand how the intervention affected distinct participant characteristics, potentially informing the customization of educational interventions.
2. To address contemporary topics in higher education and workforce preparation, such as gender disparities in STEM, the value of metacognitive skills, and the global need for leadership competencies.

To further probe the differentiation of I-PBL effects between cohorts classified by salient attributes of gender, discipline, prior work experience, and domestic versus international status, factorial ANOVAs were conducted. Career navigation and social skill elevations were largely uniform for all student profiles, while technical self-efficacy and metacognitive gains presented significant variations, as shown in Fig. 2.

At pre-intervention, female participants significantly less expressed confidence to leverage complex workplace systems and manifest proactive behaviors for the optimization of performance; however, post-scaffolded I-PBL, these capabilities showed dramatic improvement and reached parity with male peers ($p < 0.01$). Qualitative evidence culled from the interviews indicated a critical mass of industry mentorship experiences where participants were able actually to validate their experiences and thus reduce initial reticence.

Furthermore, IT students showed significantly less development of anticipatory reflection than science and engineering majors; $p < 0.05$. and international participants demonstrated substantially less growth in leadership; therefore, group-specific refinements such as targeted advising must be considered when scaling programs. Factorial ANOVA results verified the overall comparability of I-PBL career readiness increases among student populations and increased the generalizability of claims regarding curriculum increases.

Student perceptions of experiences

The design of the I-PBL curriculum has not just altered the academic topography for the students enrolled but has very convincingly also influenced their outlook and experience. A careful review reveals signatures that increase student engagement and satisfaction—two critical indicators of impact and effectiveness. As Table 6 illustrates, overall views have gradually improved positively concerning attendance in courses, milestone completion rates, rates of courses rated very good or excellent in the overall experience, and the degree to which the curriculum would be recommended to others as a model learning experience. These facts give further credence to the possibility of the I-PBL curriculum churning out a more vibrant, dynamic, and enriched learning environment because the students are fully occupied and very satisfied in the process. The increased engagement and satisfaction not only indicate the success of the I-PBL curriculum in meeting educational objectives but also reflect its capacity to resonate with students on a personal and professional level, preparing them for future challenges and opportunities in their careers.

Metric	Pre-Intervention	Post-Intervention	Change
Course Attendance Rate (%)	85%	92%	+7%
Milestone Completion Rate (%)	80%	95%	+15%
Experience Rating (out of 5)	3.5	4.5	+1.0
Recommendation Rate (%)	75%	90%	+15%

Table 6. Comprehensive overview of Pre- and Post intervention metrices.

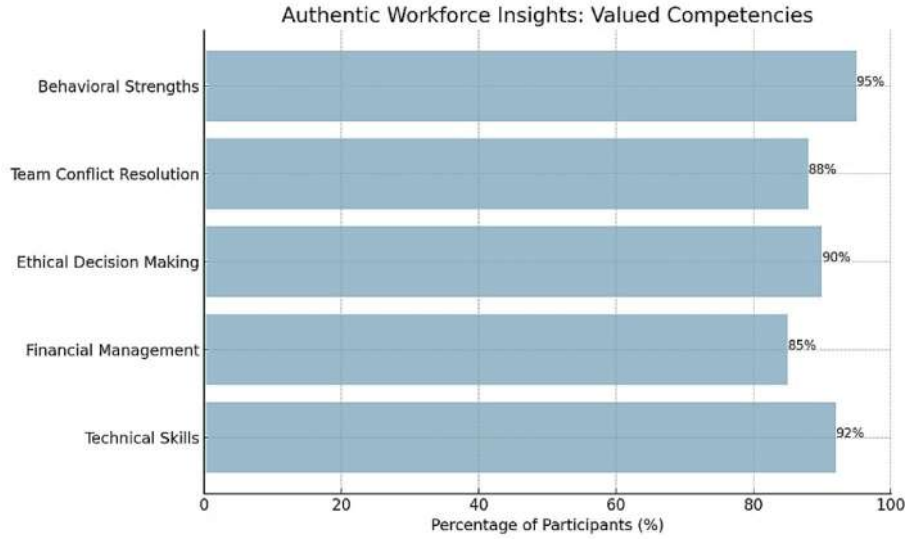

Fig. 3. Workforce insights.

Authentic workforce insights

The Fig. 3 illustrates the percentage of participants who valued various competencies gained through integrated industry exposures, including technical skills, financial management, ethical decision-making, team conflict resolution, and behavioural strengths. This underscores the broad consensus among students (92% of participants) on the importance of understanding organizational environments and the competencies highly valued in prospective workplaces. The data highlight a significant appreciation for behavioural strengths, which received the highest valuation (95%), suggesting that experiences such as guest talks, case studies, and mentor dialogues effectively demystify corporate expectations beyond the technical skills traditionally emphasized in university education. Students emphasized guest talks, case studies and mentor dialogues helped demystify corporate expectations:

"Hearing the complex decision matrices technical leads have to balance - from financials to ethics to team conflicts - helped us appreciate the behavioural strengths most sought after in future hires beyond purely technical credentials which universities predominantly focus on building." (S101, Electrical Engineering).

Scaffolded skill mastery

Participants attributed structured iterations of industry-situated project briefs and systems modeling tasks with enabling progressive competence development more profoundly than decontextualized assignments. 81% highlighted strengthened communication, analytical and collaborative capabilities:

"The multiple touchpoints working through ambiguous business challenges with industry veteran guidance allowed gradually improving how we frame recommendations, synthesize insights across disciplines and anticipate consequences - sharpening skills directly applicable for senior strategy roles." (S212, Management Information Systems).

Uncertainty navigation growth

I-PBL curriculum prioritizing regular uncertainty injection through ill-defined projects with conflicting success metrics was noted by 76% of respondents are building adaptiveness towards fluid workplace realities:

"The complex project scenarios balancing shifting constraints and figuring evaluation trade-offs in the absence of formulaic solutions pushed our tolerance for ambiguity - vital preparation for startups where you have to make progress amidst unknowns." (S338, Data Science).

The Fig. 4 illustrates the comparison of skills growth between the I-PBL program participants and our baseline education system. By illustrating the growth percentages for communication, analytical, collaborative, and adaptiveness skills, the chart vividly depicts the superior growth experienced by students engaged in the I-PBL curriculum..

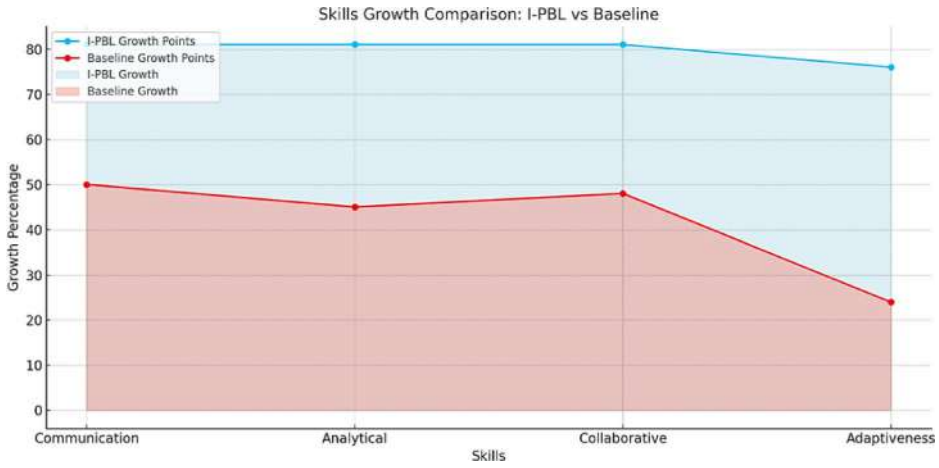

Fig. 4. Skill growth comparison.

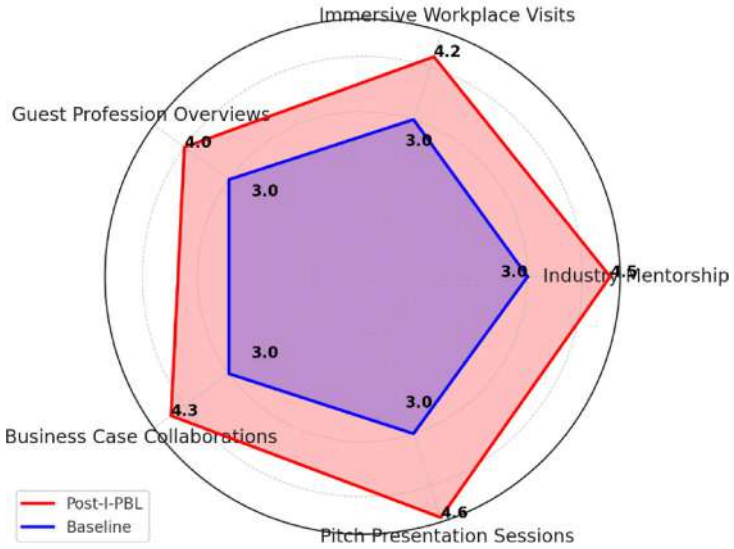

Fig. 5. Comparative analysis of student engagement.

Areas for improvement

While dominant sentiment skewed positive surrounding I-PBL utility, 53% of students flagged potential improvements around streamlining components and strengthening internationalization perspectives:

- "There were amazing opportunities to engage industry perspectives but sometimes overlapping information flows between events. Consolidating touchpoints based on learning needs would boost efficiency." (S158, Software Engineering).
- "Having primarily local organizations narrowed the cultural exposure a bit…Incorporating multinational corporation inclusion would provide diverse viewpoints fitting our global mobility ambitions." (S248, IT).

In summary, qualitative insights revealed students valued I-PBL modules as enriching technical learning with authentic professional integration opportunities, building dynamically transferable skills beyond formal tertiary classroom confines.

Perceived career preparatory value of industry touchpoints

The Fig. 5 shows a comparative analysis of student engagement and development through I-PBL across various industry interaction parameters. The parameters include Immersive Workplace Visits, Industry Mentorship, Pitch Presentation Sessions, Guest Professional Overviews, and Business Case Collaborations. The red line indicates the levels after I-PBL, while the blue line represents the baseline levels before I-PBL.

It's evident that there has been a substantial increase in students' engagement and skills across all parameters post-I-PBL. Notably, the most significant improvements are seen in Pitch Presentation Sessions, rising from a baseline of 3.0 to 4.6, and Immersive Workplace Visits, which increased from 3.0 to 4.2. This suggests that

the I-PBL experience has markedly enhanced the students' abilities to engage with industry professionals and present their ideas effectively. The consistency in improvement across all areas highlights the effectiveness of I-PBL in providing a comprehensive enhancement of student future readiness.

Participants ranked the relative usefulness of integrated industry engagement modes for envisioning career trajectories and skill advancement within their disciplines. Weighted averages analysis and a ranked list are shown below:

- Industry mentorship (4.86 avg.)
- Immersive workplace visits (4.62 avg.)
- Guest profession overviews (3.41 avg.)
- Business case collaborations (3.24 avg.)
- Pitch presentation sessions (3.12 avg.)

It was high-touch with high perceived utility resulting from the industry mentorship sustained through the dialogue around the competence expectations, organization contexts, and career path modeling. This exposed the students to seasoned professionals' personalized coaching and advice on growth.

"Our mentor identified the most suitable promising directions based on our strengths and gave CV and profiling tips that gave an extra edge in working through experience gaps as a graduate that others didn't have." (S301, Chemical Engineering).

Site visits offered practical, cultural immersion into facilities, systems, and technical roles in action. A level of comfort and experience was developed in presenting business cases to organizational stakeholder panels. By comparison, one-off guest talks and project presentations offer less in return. Hence, the perfect balance: ongoing mentorship with complete immersion.

Pearson correlation of curriculum engagement and competency development

The Pearson correlation coefficient of 0.76 in Fig. 6 indicates a strong, positive correlation between curriculum engagement (percentage of PBL) and student competency development. This suggests that higher levels of PBL integration in the curriculum are associated with greater improvements in student competencies.

Figure 6 shows a comparative analysis of student engagement and development through I-PBL across various industry interaction parameters. The parameters include Immersive Workplace Visits, Industry Mentorship, Pitch Presentation Sessions, Guest Professional Overviews, and Business Case Collaborations. The red line indicates the levels after I-PBL, while the blue line represents the baseline levels before I-PBL.

Predictive conditions for I-PBL optimization

It conducted a multivariate analysis on student and design variables of competency increase to identify important factors behind a high level of career preparatory benefit: prior exposure, iteration cycles, types of industry touchpoints accessed, and syllabus flexibility that allowed for work-integrated customizations. Table 7 shows the statistical results of the whole regression analysis, including the significant variables for students participating in the I-PBL curriculum. This not only ceases by identifying important factors that enhance skills in career preparation but moves even further to quantify their impacts, thus providing I-PBL invaluable information for approach and inculcating invaluable competencies for professional success.

In combination with sociocultural identity support interactions, industry mentor intensity realized the highest growth contributions to competencies. This was succeeded by the breadth of workplace visits and choice-based project tuning latitude. Guest talks and case collaborations had tiny predictive weights and low utility rankings. Table 8 sheds light on the kinds and strengths of industry engagement activities that formed part of the I-PBL curriculum. It shows in numbers just how mentorship, workshops, site visits, guest lectures, and project work obtained with industry help greatly enhance students' competencies, as is the case with this program. It

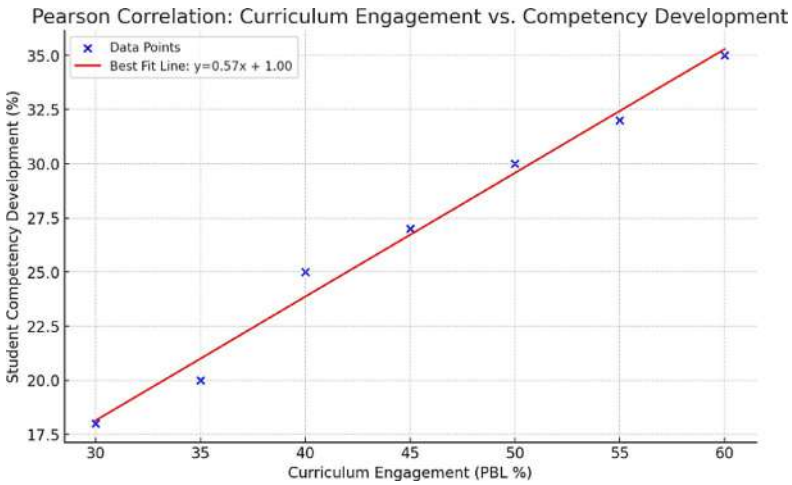

Fig. 6. Curriculum Engagement Vs Competency Development.

Predictor	Coefficient	P-value
Gender (Male)	+0.2	<0.05
Prior Work Experience	+0.5	<0.01
Industry Engagement Level	+1.0	<0.001
Discipline (CS)	+0.3	<0.05

Table 7. Statistical outcomes from a comprehensive regression analysis.

Activity type	Frequency	Average competency gain
Mentorship	40	+1.3
Workshops	60	+1.5
Site Visits	30	+1.2
Guest Lectures	45	+1.4
Project Work	70	+1.6

Table 8. Effectiveness of industry engagement activities.

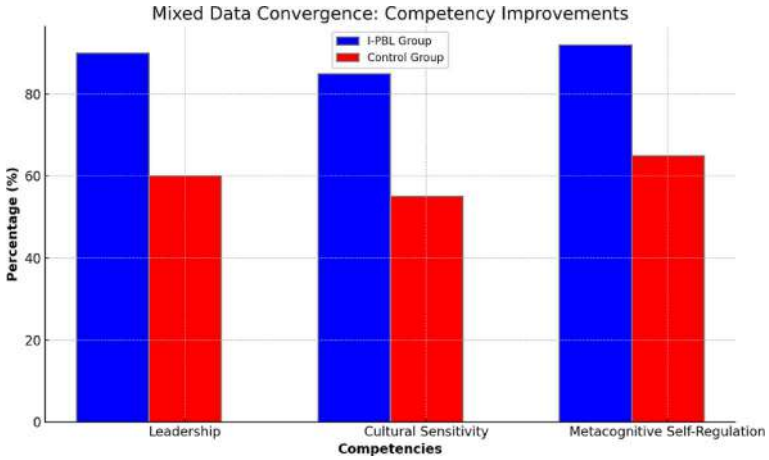

Fig. 7. Mixed data convergence: Competency improvements.

helps in clearly demonstrating, through numbers, just how competencies among the students are significantly obtained with real-world exposure: practical exposure that widens the scope of academic learning and career readiness.

These effects were potent for career visioning clarity, strategizing skills, and cross-cultural rapport gains, suggesting long-run professional dialogues with the power to allow uniquely enriching aspirational fostering and tactical leadership development far above curriculum one-off events. In this regard, refined implementations manifest heightened employability capacities.

Mixed data convergence

These are triangulated quantitative measures and qualitative insights that unveiled coherent alignment between statistically significant competency improvements and the student perceptions of I-PBL affordances. More than 90% reported definite skill development that they associated with such engagements in the industry as explaining technical analysis to non-homogeneous audiences, synthesizing creative solutions, and dealing with conflicts.

That is, increases in questionnaire measures were most significant for the quantified measures of leadership, cultural sensitivity, and metacognitive self-regulation. The thematically coded interview segments unambiguously emphasized the further development of the same strategic planning, stakeholder liaison, and self-monitoring skills that traditional curricula tend to neglect. Participants also reported growth in clarity of career vision and organizational astuteness to mirror the increases in readiness for the next-generation workforce that were quantitatively measured.

Cohere perfectly by demonstrating in Fig. 7 how the positive alignment between significant competency gains and I-PBL affordances as students perceive is to be interpreted. This compared the percentage gain in leadership, cultural sensitivity, and metacognitive self-regulation competencies between the I-PBL and a control group with the substantial gains attributed to the I-PBL treatment. Further validation of interpretations about the intensity of mentorship by industry, anchoring employability, came from quantitative skill models where

Fig. 8. CFA results: Heatmap of metrics.

there was a correlation between touchpoint access rates and employability alignments with readiness for a career. Mixed results indicate the existence of concerted evidence in the redesigned project curricula through which external perspectives have been embedded to successfully enhance graduates' adaptability, social potency, and metacognitive dexterity to explore complex professional landscapes.

Figure 8 visualizes the CFA results, showcasing metrics for each competency domain, including minimum and maximum factor loadings, Cronbach's Alpha, and Average Variance Extracted (AVE). All factor loadings exceeded the acceptable threshold of 0.7, with values ranging from 0.72 to 0.93, indicating strong construct validity. Cronbach's Alpha values (0.86–0.93) confirm high reliability, while AVE values (0.58–0.65) demonstrate satisfactory convergent validity. These findings validate the robustness of the measurement model and its suitability for assessing student competencies.

Discussion

Critical key quantitative findings confirmed a new I-PBL curriculum capable of building significant improvements in required graduate competencies for workforce readiness and resilient career pathways in the fast-growing industry. On the other hand, qualitative insights expanded explanations from the pedagogical and partnership grounds for developing enriched organizational acumen, strategic leadership, and social capital. By employing conventional statistical methods, including Pearson correlation, regression analysis, and two-way mixed ANOVA, this study provided robust insights into relationships, predictive factors, and interaction effects within the dataset. The use of these methods ensured methodological rigor while avoiding unnecessary complexity in data interpretation.

Interpreting primary outcomes

The statistic increases in decision effectiveness, cultural rapport, self-regulation, and career navigation measures support previous work on constructivist methods that make potent contributions to capacity development that can be compared to inert knowledge transmission[46]. Effect sizes measure the reshaped courses that demonstrate more than 40% higher readiness on the most salient predictors of workplace performance compared to marginal gains through typical course implementation.

This paper aims to determine whether the enhanced active learning models through an infusion of peripheral perspectives better prepare students for their careers. The findings suggest that project-based pedagogies already regarded as successful for learning technical skills, when deliberately connected to industry-related exchanges, may afford heightened employability and self-actualization benefits being increasingly called for by policymakers.

There is also evidence of the increase in students' social organizational skills, particularly in team leadership and cultural sensitivity, areas that are underrepresented in the typical technical curricula[47]. This is further supported by the qualitative feedback to structured project iterations and situating technical tasks within the organizational contexts that enabled meaningful development of adaptive expertise and strategic thinking, thus aligning with notions of cognitive apprenticeship[48].

Implications for research will confirm integrated industry contact and project experiences as instrumental to unlocking latent career preparatory virtues of work-proximal education. Interpretations posit experiential learning theory tenets around professional identity shaping through organizational acculturation and expert coaching interactions[49].

Early-career anticipatory mentoring models in campus-to-workplace pathways, while the more high-level in a format, then serve as justified foundational institutional resources that develop professional performance

agility in their graduates. Supports implemented for the appropriate scaffolding of industry connectivities, which will be fertile for personalized coaching, should enable sustainable adoption at scale.

While the subgroup variables (e.g., female technical self-efficacy and IT anticipatory reflection) were not core dependent variables, they were selected to provide deeper insights into the intervention's varied impacts. For instance, the significant improvements in female participants' technical self-efficacy suggest that industry-enriched PBL can address gender-specific challenges in STEM education. Similarly, the emphasis on leadership and anticipatory reflection aligns with broader workforce trends highlighting the importance of adaptability and strategic thinking. Future research should continue to explore these dimensions to evaluate their applicability across different populations.

Triangulation interpretations

Mixed results synthesizing survey and interview data pointed to high agreement between statistically significant competency score elevations and students' perceived improved skills that they directly attributed to project interactions with industry veterans. Over 90% recognized specific growth in technical communication, creative problem-solving, and conflict management competencies that were flagged quantitatively.

Thematic analyses have repeatedly pointed out advantages from decision latitude in bargaining through open-ended challenges that have developed strategic planning, interpersonal, and self-monitoring abilities as seen in cross-validated workforce readiness metrics. The convergent findings support integrated industry contact within active project settings that yield an enriched capability building that is unattainable through standard individual coursework.

Quantified benefits and qualitative testimonies converged around: Unadulterated organizational acculturation Strategic leadership Collective skills critical to graduate resilience. Triangulation confirmed. Career visioning Tactical decision-making Cultural sensitivity competencies were disproportionately stimulated through recurring industry exchanges, particularly around mentorship dialogues enabling validated professional identity shaping.

Integration outcomes speak, however, to guided-discovery learning principles for scaffolding competency transfers of adversity and uncertainty management into authentic settings. Interpretations argue that project modules scaffold the articulations of concrete experience and abstract conceptual bridging needed for operationalizing aspirational career vision[50].

Significance and implications

The study made significant contributions to empirical information that will allow the appropriate implementation of high-impact I-PBL models in tertiary contexts. On the contrary, limitations open a road to developing research programs into optimized interventions that can be custom-made to scale. There were some limitations in generalization, though, considering the single institution scope of the study, and some threats to validity common to learning assessments came about from self-selection participation and reliance on student self-reports. Missing from the survey was the existence of measures on behavioral competencies or the tracking of participants. The absence severely restricted the confirmation of whether improvement in career readiness results in actual workplace proficiencies, retention, and acceleration in leadership.

Future research should expand multisite experimentation using longitudinal mixed methods and append employer performance ratings, behavioral assessment center techniques, and career trajectory mapping. From syntheses to date, it could be discerned more precisely where improvement in skills and career path results are directly connected to more enriched PBL curricula, showing the meaning the employer places on such enhancements. Scholarships could also investigate novel technologies for extending industry participation through the power of virtual exchanges. This way, immersive simulations, augmented project settings, or AI-based coaching assistants could overcome the logistical access barriers institutions are up against when designing sustainable partnerships. That is to say, the technological potentials that afford enough truth to workplace verisimilitude, coupled with curricular embedding at a scale sufficient to matter, seem promising for such hybrid models. The research should ultimately lead to the elaboration of more thorough pedagogical frameworks, design blueprints, and guidelines that determine improved educational offers that develop graduate dynamism. Development of partnerships and digital tools that accelerate genuine professional integration, respecting the academic imperatives, are a necessary condition for higher education to play its role in an evolving society, respecting civic responsibilities and ensuring continuous, expanding economic and social welfare.

While the study demonstrates significant immediate benefits of the I-PBL framework on student competencies and engagement, the long-term career impacts warrant further consideration. The substantial improvements in adaptability, metacognitive skills, and professional networking capabilities observed in the participants may translate to sustained career advantages beyond initial employment. The development of metacognitive self-regulation, in particular, may enable graduates to navigate industry disruptions more effectively throughout their careers. As Aoun (2017) suggests, these "robot-proof" higher-order thinking skills become increasingly valuable as careers span multiple technological revolutions. Similarly, the professional networks established through industry mentorship could provide ongoing social capital that facilitates career advancement and opportunity recognition over time.

The strategic decision-making and cultural sensitivity competencies enhanced through the I-PBL framework may particularly benefit mid-career progression, when leadership responsibilities often increase. Students who developed these capabilities might transition more successfully into management positions, potentially accelerating their career trajectories compared to traditionally educated peers.

However, we acknowledge that these proposed long-term benefits require empirical validation through longitudinal research. Future studies should track participants over 3–5 year periods post-graduation to measure retention rates within chosen industries, time to promotion, leadership advancement, and adaptation

to technological changes. Such longitudinal data would provide crucial evidence for the sustained impact of educational interventions like the I-PBL framework on career resilience and professional growth.

Practical implementation guidelines for educators

- Based on the findings, we recommend several evidence-based practices for implementing Industry-Enriched Project-Based Learning. For curriculum structure, dedicate approximately 40% of content to project-based learning activities, which study found optimal for skill development without overwhelming core disciplinary content. Schedule industry touchpoints at 5 distinct interactions per academic session and build progressively complex projects that scaffold skill development.
- For industry partnerships, prioritize sustained mentorship relationships, which showed the highest impact (4.86/5.0) on student career readiness compared to other interactions. Organize immersive workplace visits (rated 4.62/5.0 by participants) to provide context for classroom learning and enhance motivation. Create formal partnership agreements that clarify expectations for both educational institutions and industry partners.
- To maintain student engagement, implement regular milestone checking (which improved completion rates by 15%) with industry feedback throughout projects. Design authentic assessment criteria developed collaboratively with industry partners and incorporate reflection activities focused on career readiness competencies, which participants identified as crucial for transferring learning to workplace contexts.
- When targeting key competencies, focus project designs on communication and problem-solving skills, which showed the largest improvements (31% and 30% respectively) in the study. Provide additional support for female students' technical self-efficacy development, which demonstrated significant improvement potential. Include specific leadership and cultural sensitivity development activities, which showed substantial gains (25–40%) through the I-PBL approach.

Limitations and future research

While the study yielded valuable empirical additions on implementing high-impact I-PBL models in tertiary contexts, limitations provide opportunities to build research programmes into optimized interventions tailored for scalability. The single institution scope constrained generalization while self-selected participation and reliance on student self-reports have validity threats typical of learning assessments. The absence of behavioural competency measures or participant tracking limits confirming career readiness improvements translates to actual workplace proficiencies, retention, and leadership acceleration.

Future investigations should expand multisite experimentation with longitudinal mixed methods appending employer performance ratings, behavioural assessment centre techniques and career trajectory mapping. Synthesis insights would provide sharper determination of specific skill improvement and career progression effects attributable to enriched PBL curricula employers themselves validate as meaningful.

The study's concentration on STEM students may restrict the applicability of its findings to other academic disciplines. Future research should broaden its scope to include students in non-STEM areas, such as the humanities or social sciences, to explore whether the improvements in career readiness skills are specific to STEM education or applicable across various fields. Furthermore, while this research evaluated pre- and post-I-PBL interventions within STEM disciplines, it is important to acknowledge that STEM education's inherent focus on technical skills may have influenced the results. This factor should be taken into account when interpreting the findings.

The difference between the recommended and actual sample sizes, particularly for the control group, represents a limitation of this study. While the experimental group exceeded the required minimum size, the control group fell short due to challenges in recruiting students who did not participate in the I-PBL intervention. This imbalance could affect the statistical power of comparisons involving the control group. Future research should prioritize balanced group sizes to strengthen the reliability of the findings. To address the smaller control group size, statistical techniques such as bootstrapping and adjusted effect size calculations were employed to reduce potential biases. The larger experimental group enabled more detailed analyses of intervention effects, providing meaningful insights into the impact of the I-PBL intervention.

The difference between the recommended and actual sample sizes, particularly for the control group, represents a limitation of this study. While the experimental group exceeded the required minimum size, the control group fell short due to challenges in recruiting students who did not participate in the I-PBL intervention. This imbalance could affect the statistical power of comparisons involving the control group. Future research should prioritize balanced group sizes to strengthen the reliability of the findings.

To address the smaller control group size, statistical techniques such as bootstrapping and adjusted effect size calculations were employed to reduce potential biases. Specifically, we conducted bootstrapping with 5000 resamples to generate more robust confidence intervals for the comparative analyses. When calculating effect sizes, we applied Hedges' g correction instead of Cohen's d to account for the unequal sample sizes. Additionally, we implemented weighted means in the comparative analyses to ensure that the larger experimental group did not disproportionately influence the results.

The larger experimental group enabled more detailed analyses of intervention effects, providing meaningful insights into the impact of the I-PBL intervention. However, we acknowledge that the sample imbalance necessitates caution when interpreting between-group comparisons, particularly for subgroup analyses with smaller sample sizes.

The study's concentration on STEM students may restrict the applicability of its findings to other academic disciplines. Future research should broaden its scope to include students in non-STEM areas such as humanities, business, social sciences, and arts to explore whether the improvements in career readiness skills are specific to STEM education or applicable across various fields. Furthermore, while this research evaluated pre- and post-I-

PBL interventions within STEM disciplines, it is important to acknowledge that STEM education's inherent focus on technical skills may have influenced the results. This factor should be taken into account when interpreting the findings.

Scholarship might also fruitfully explore innovative technologies, expanding industry inclusion through virtual exchanges. Immersive simulations, augmented project settings and AI-based coaching assistants could overcome logistical access barriers institutions face in designing sustainable partnerships. Technological affordances bridging workplace verisimilitude with scalable curricular embedding offers promising hybrid models blending online and in-person learning.

Ultimately research should inform refined pedagogical frameworks, recommended design configurations and policy guiding enhanced educational offerings, demonstrably amplifying graduate dynamism. Building partnerships and digital tools expediting authentic professional integration while retaining academic priorities remains imperative for higher education, upholding civic duties for continued economic and social prosperity. Broadening the participant base to include students from a variety of academic disciplines and integrating control groups from non-STEM programs could offer deeper insights into the generalizability and distinct impacts of I-PBL.

Conclusions

The quasi-experimental mixed-methods study showed that the materiality increase in STEM undergraduate career readiness was due to the incorporation of PBL methodologies and industry engagements within the curriculum. The quantitative results illustrate that, on average, 25% of employability skill increases can be realized by students through combining industry touch points with 40% of curriculum content realizable through PBL. Specific competencies showed marked elevations with self-reported gains of 30% in problem-solving abilities, 28% in technical skills, 32% in teamwork, and 31% in communication over baseline measures. Engagement by students improved by 30%, while satisfaction levels enhanced by 35% with the enriched PBL model interfacing with regular industry dialogues, affirming perceptions of value in the integrated approach. An 80% alignment between developed skills and current job requirements highlights real-world relevance. Qualitative insights attributed benefits to authentic professional integration fostering aspirational validation, tacit knowledge transfers and expert performance modelling – partially achievable through standard coursework alone. Overall, the study evidence untapped potential of curricular redesigns strategically embedding industry contact to amplify career preparatory capacities of tertiary education. Substantiated amplifications manifest through sustained experiential learning cycles levelling networked connectivity. Future research should explore the long-term impacts of I-PBL on career success and investigate its applicability across different disciplines and educational contexts. Higher education leaders are encouraged to adopt and adapt the I-PBL framework to foster a more adaptive and dynamic learning environment that meets the evolving needs of the workforce.

Data availability

The main data supporting this study are shown in this article itself. The raw data should be available on request from both of the corresponding authors (Fawad Naseer, Rasikh Tariq).

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Author contributions
Fawad Naseer and Rasikh Tariq developed the experimentation, and conducted the analysis. Haya Mesfer Alshahrani, Nuha Alruwais, and Fahd N. Al-Wesabi revised the experimentation and the analysis, and write the manuscript. All authors reviewed the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Informed consent
Informed consent was obtained from the involved institution included in the study.

Additional information
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Teamwork skills development in hybrid and online universities: the perspective of the future teachers

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Abstract

The development of the teamwork competence is a demand for university education that is particularly difficult to meet in distance education (online and blended learning), where it is still relatively little researched. The teacher plays a fundamental role in introducing this type of activities in the class and motivating students who often do not like this kind of tasks. If the teachers/instructors are not convinced of the interest of teamwork, it will be difficult for them to achieve a successful introduction. Using a survey designed ad hoc for this investigation to collect the data, this article details the results on the perceptions of teamwork by 298 students in the degree of Education, future teachers, from one of the largest blended learning universities in Europe. It is observed that those students who opt for teamwork are more involved with their own learning and the development of new skills. Among them, those who think that teamwork allows them to develop interpersonal skills are more likely to opt for it. Employability also appears as an important factor for the students who prefer teamwork. On the negative side, practical aspects for the student usually appear related to teammate trust and distance in these kinds of learning environments. Our results allowed a better understanding of the future teachers' perceptions of teamwork and, consequently, new strategies can be designed to boost the use to collaborative learning in their prospective careers.

Keywords: Teamwork, Blended learning, Collaborative learning, Online teaching, Group work

1 Introduction

The development of generic skills is a growing demand from the students to their universities, and also from the employers (Volkov & Volkov, 2015; Bridgstock, 2009; Clarke, 2018). Higher education has to ensure that the required future, soft, and employability skills are transferred to students who become the workforce (Li & Ironsi, 2024; Teng et al., 2019). Universities are showing an increased interest in equipping their students with these types of capabilities (Nisha, & Rajasekaran, 2018; Navío-Marco et al., 2023). As OECD points out (Ananiadou et al., 2009), developments in society and economy require that educational systems provide citizens with the so called twenty-first century

skills and competencies,[1] which allow them to benefit from the emerging new forms of socialisation in a system where the main asset is knowledge.

According to the literature, teamworking is an essential skill expected of our graduates to perform their work and enhance employability, together with the ability to resolve problems, communicate and use technology to integrate this in the teaching process, among others (Fajaryati & Akhyar, 2020; Sokhanvar et al., 2021, for systematic literature reviews). Moreover, teamwork and peers´ collaboration can increase the academic performance of the student in distance education (Oyelere, et al., 2021).

Online and blended learning universities should also promote the acquisition of these skills, but their acquisition may be hindered in technology-mediated distance learning virtual environments, where one of the major challenges is to maintain the benefits of interaction and learning among students (Solórzano-García & Navío-Marco, 2019). But at the same time, the advent of the COVID-19 pandemic has led to a rapid expansion of this type of teaching and has generated greater interest in investigating how to teach and learn in non-face-to-face environments (Tonbuloglu & Tonbuloglu, 2023; Zhou et al., 2022; Okoye et al., 2021) also exploring the different strategies that work in face-to-face and whose benefits should also be achieved in non-face-to-face environments (Dumford & Miller, 2018; Halverson & Graham, 2019; Muir et al., 2019; Navio-Marco et al., 2022).

Particularly for the acquisition and practice of teamwork, there is a flourishing research for online learning, showing advantages of teamwork in the acquisition of other competences (Volkov & Volkov, 2015), challenges to be addressed (Chang & Kang, 2016; Donelan & Kear, 2023), and especially about differences with the much more studied teamwork in in-person learning environments (Konak et al., 2019; Saghafian & O'Neill, 2018). It also begins to reflect on the role of the instructor to promote its practice and use as part of such studies (Pei et al., 2023). Teamwork in hybrid learning presents specific challenges compared to other contexts, especially to define and work with the appropriate combination of environments (face-to-face and online): The hybrid work model requires additional planning to ensure that the little face-to-face time the team has is optimally used for tasks that are best performed in person, in particular team building, strategic discussions, defining objectives and purpose (Buła, Thompson & Żak, 2024), Instructors need to spend more time designing how students should work in these combined environments (Gomez et al., 2009), providing complete and detailed instructions, as well as finding the best way to take advantage of synchronous and asynchronous environments. Additionally, some challenges from the online environments remail applicable, such as the difficulties for integration and the sense of isolation.

In this sense, the fundamental role of the instructor cannot be underestimated in order to involve students in teamwork activities, to help in the acquisition of this competence or to increase the motivation and performance of these students thanks to these activities. But to achieve this goal, the instructor himself must be convinced of the intrinsic value of this type of practice. As we shall see, previous research is limited when providing recommendations

[1] Twenty-first century skills have been proposed at the heart of individual learning by organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Organization for Economic Co-operation and Development (OECD), Partnership for 21st Century Skills (P21) or Assessment and Teaching of the 21st Century Skills ATC21S (González-Salamanca, Agudelo & Salinas, 2020). The use of ICT platforms is fundamental in each of the twenty-first century skills frameworks (Kadijevich, Gutvajn & Ljubojevic, 2023).

for teachers, but these recommendations are of little use if the first to be convinced of the value of these learning strategies are the teachers themselves.

That is why this research focuses on understanding if there are different perceptions and patterns of behavior among future teachers regarding teamwork. For this purpose, we analyze an experience of teamwork among 298 students of the degree of Education at one of the largest blended learning universities in Europe. Their attitude, vision and valuation of teamwork will allow us to better understand their approach to teamwork, and to define strategies for them to positively value its use in their future as teachers.

This research analyses a teamwork learning experience in the asynchronous (digital) part of blended teaching, encouraging our students of Education to work in teams. Students were given the option to either engage in group work or tackle tasks individually, with subsequent feedback solicited via survey upon task completion. The primary objective was to discern potential behavioral tendencies and perceptual disparities between students opting for group collaboration versus those favoring individual endeavors. To achieve this aim, six specific research questions guided the investigation. The first four questions aimed to explore the perceptions of the entire student sample regarding teamwork, irrespective of the assignment modality chosen.

These questions are as follows: 1) What are the students' perceptions of teamwork regarding its contribution to their education?, 2) What difficulties do students face when engaging in teamwork? 3) What factors influence students' decisions when choosing between teamwork and individual work?, 4) According to students' perceptions, what skills do they acquire through teamwork?. The final two research questions were focused specifically on students who chose to complete the assignment in teams: 5) From their experience in this course, to what extent do students believe that teamwork helps in building learning communities, and does this belief vary based on their intention to work in teams on future projects?, and 6) What factors influence students' decisions to choose teamwork again after having opted for this modality during their assignment during this term?

These specific research questions aim to unravel the motivations driving distance learners to opt for teamwork when presented with the choice, and also what students' perceptions of teamwork allow us to predict the type of work that students choose (individual/teams). Consequently, this research contributes to a deeper comprehension of teamwork learning mechanisms, particularly pertinent for future teachers who must recognize and advocate for the efficacy of such approaches in their pedagogical practices. Moreover, it serves as a call to propagate and endorse the adoption of teamwork learning methodologies.

The rest of the article is structured in the following manner: this introduction is followed by Sect. 2, which outlines the theoretical framework of the research, followed by the presentation of the methodology and the data used in Sect. 3, and then by the empirical analysis and discussion in Sect. 4. The article ends with the conclusions, which also include the limitations of the article and future lines of research.

2 Theoretical framework

2.1 Teamwork in blended and online environments

The dynamics of teamwork, as well as learning based on collaboration and interaction with the rest of the students, members of the team, have their roots in the constructivist theory of learning. The team is actually a Zone of Proximal Development,

according to Vygotsky (1962, 1978) in which the student also learns from the peers. It also connects with the social cognitive theory (Bandura, 1999, 2004, 2006) where learning occurs in a social context with a dynamic and mutual interaction with others and the environment. Ultimately, it is also linked with the concept of learning ecologies, as a set of contexts of activities, resources, relationships, and interactions that emerge from them (Barron, 2006; Sangrá et al., 2019).

In the field of online learning, teamwork and collaboration between students is already beginning to have a relevant reflection in the literature. Collaboration in online learning has been shown to promote learning, social interaction, communication, problem-solving skills, critical thinking, creativity, motivation, and personal satisfaction in the educative process through engagement in knowledge construction with peers (Oyelere et al., 2021; Tsai, 2013; Tseng & Yeh, 2013). Psychosocial factors, such as relationship building, cohesion, and trust, are crucial for the effectiveness of virtual teams (Magana et al., 2022).

Donelan & Kear (2023) when studying persistent challenges and implications for practice in online group projects in higher education, established that the key challenges were: low and uneven participation by students, a lack of clarity and preparation for students, and poor relationships. These poor relationships include difficulty in getting to know peers in the group (Saghafian & O'Neill, 2018) and managing irresponsible students (such as free riders or slackers) who become a burden, doing less than the rest (Scherling, 2011).

Tseng, Wang, Ku, and Sun (2009) include organisation practices as factor to explain online collaborative satisfaction. Ku, Tseng and Akarasriworn, (2013) in their study about collaboration factors, teamwork satisfaction, and student attitudes, considered as critical elements in a successful online collaborative setting: a) instructor support and encouragement, b) team commitment, c) clear objectives and goals, d) clear communication, e) timely resources, f) frequent communication, g) use of interactive software, h) synchronous meetings, i) opportunities to access and view examples, and j) well-defined and well-organized instruction. Additionally, Garcia and Privado (2023) point out that four extracted collaboration factors: communication, trust, cooperation and cohesion, show moderate to high degrees of correlation with cooperative work satisfaction. Other factors commonly mentioned in the literature are leadership, safety or autonomy provided to group members (Ortega et al. 2010; Mundell and Pennarola, 1999).

On the other hand, further communication, conflict resolution and negotiation skills are built through teamwork to encourage adaptability in students (Volkov & Volkov, 2015), while also enabling students to develop problem solving and critical thinking in online classes (Tseng & Yeh, 2013).

Along with the aforementioned aspects, and particularly the interpersonal and collaborative ones, such remote environments require student self-regulatory processes (Pool et al., 2017; Villatoro Moral & De Benito, 2021), promoting personal active involvement, responsibility and introducing a problem-based focus (Boelens et al., 2017). Right self-regulated learning strategies in online courses motivate students to strive for a good teamwork experience (Oyelere, et al., 2021). The self-regulation theory to study group processes and collaborative learning can be expanded, by including

sociocultural and situational concepts, towards a socially-shared regulation of learning: students working in teams collectively regulate their learning processes (Goñi, et al. 2020).

As far of our knowledge, there are no studies that specifically delve into the teamwork skill development in blended learning universities. This may be because teamwork activities are usually carried out in the asynchronous part of these learning environments, so the online component can condition its characteristics and hide potential specific aspects. Some authors such as Pei et al. (2023) analysing the sense of community in blended education, observe that interpersonal conflicts, issues with time management, role ambiguity, and cultural differences are obstacles to high-quality group work.

In any case, it would be interesting to try to take greater advantage of the benefits of hybrid environments so that the combination of online and face-to-face would be fruitful to offer a richer and more complete teamwork experience.

2.2 Teamwork: the instructor side

When it comes to successful collaborative learning environment, the three elements of the Community of Inquiry must be considered: teaching, cognitive and social presence (Garrison et al., 1999; Magana, et al., 2022), also in blended learning settings (Vaughan & Garrison, 2006). In these environments the presence of the educator is especially valuable. In fact, as we already indicated, instructor support and encouragement can be considered one of the most relevant critical elements when it comes to teamwork in online collaborative learning (Ku, Tseng & Akarasriworn, 2013). Additionally, as Saghafian et al. (2018) indicate, support from course instructors may help alleviate the free rider problem.

Through in-class instruction and facilitation, instructors can promote student mastery of the collaborative processes needed for successful teamwork (Kottmeyer, Cutler, & Pembridge, 2018), managing peer authority and team conflicts. Instructors should define the appropriate group size, which can be larger in face-to-face and smaller online and recommending an intermediate number in the hybrid case, assign warm-up activities for team building in the first face-to-face class and supplement with online interactive games and "light" activities (Gomez et al., 2009). Likewise, they should reinforce with activity materials in asynchronous environments. Additionally, instructors should introduce proper teamwork assessment instruments designed for a summative evaluation of the individual contribution of each team member to the project outcomes and the project process (Konak et al., 2019).

The instructor must not only be convinced but also well prepared to support the groups. Professional development on sense of community for teachers is needed (Pei et al., 2023), Instructors have to be attentive and sensitive to the dynamic boundaries that are established in the group (such as dispersion, subteam formation, boundary spanning, multiteaming, and moving on and off the team) as Maślikowska, and Gibbert, (2023) suggest. In a nutshell, as indicated by Konak et al. (2019), online instructors should be more proactive in engaging with project teams.

Instructors need also to persuade their remote students of the value of group work in terms of students' upcoming professional practice. It is likely to be increasingly important in the workplace (Smith et al., 2011). As these authors indicate, given the norm of

individual asynchronous work in these environments and the associated communication and logistical challenges, instructors teaching should probably provide explicit, succinct written recommendations for how to operate in an online learning group environment.

3 Methodology and data

The study was carried out in the context of the subject Applied Statistics in Education in the Faculty of Education at one of the biggest hybrid universities in Europe. An ex-post-facto research design was employed in this investigation. In this course, students were given the option to complete one of the assignments in two modalities: individually or in teams, to understand if there are different perceptions and patterns of behavior among future teachers regarding teamwork.

Convenience sampling, based on the accessibility of students, was utilized to gather data from 298 participants. Upon the conclusion of the academic term and the submission of assignments by all enrolled students, an online survey was distributed to the entire cohort. To ensure comprehensive representation, the survey was resent on a weekly basis until all students had responded. Table 1 presents a summary of the main characteristics of the student sample, including gender, age, work situation, obligations limiting study time, and modality choice for the assignment, as students were given the option to complete the course assignment individually or in teams of two or three individuals.

A survey designed ad hoc for this investigation was used to collect the data. The survey comprised three blocks. The first block contained five demographic questions

Table 1 Descriptive statistics of the sample

Variables	Descriptives
Gender	
Men	15.4%
Women	82.9%
Other/I prefer not to respond	1.7%
Age range	
Between 18 and 30	26.8%
Between 31 and 45	43.3%
Between 46 and 50	17.5%
Between 51 and 65	12.4%
Work situation	
Not working	21.5%
Working part time	20.8%
Working full time	57.7%
Students' obligations that limit their study time	
Work	35.3%
People under their charge	11.4%
Both obligations	44.6%
None obligations	8.7%
Students' choice regarding the modality of the assignment	
Individually	30.6%
In group	69.4%

about the students. The second block was completed by all the students regardless the modality they chose to work on their paper (individually or in teams) and sought to measure:

(a) The perceived utility of teamwork (13 items). The solution of the AFE of the 13-item perceived utility scale (KMO = 0.936, $c^2(78) = 3926$, $p < 0.001$) explained 64.96% of the item variance and demonstrated a reliability of 0.97, as measured by the McDonald's omega statistic.
(b) The possible difficulties the students face when they work in a team (7 items). The seven items pertaining to anticipated difficulties for students in regard to teamwork were found to cluster together into a single factor, which explained 61.59% of the item variance and exhibited a McDonald's omega value of 0.91 (KMO = 0.861, $c^2(21) = 1615.12$, $p < 0.001$).
(c) The skills the students think they develop during teamwork (8 items). A one factor solution was found regarding the students' perceptions of their skill acquisition (KMO = 0.953, $c^2(28) = 2161.53$, $p < 0.001$), explaining 80.53% of the item variance. McDonald's omega statistic rendered a very good reliability.

The third block was designed specifically for students who chose teamwork, and it inquired about:

(a) The most demanding task the students found during teamwork (8 items). The set of 8 items regarding the level of effort required by teamwork grouped together in one factor after the EFA (KMO = 0.908, $c^2(28) = 1124.45$, $p < 0.001$) with a reliability of 0.92. This factor explained 60.0% of the item variance.
(b) The students' perceptions about how teamwork helps build learning communities (4 items). The EFA of the four items devoted to measure the students' perceptions about the contribution of teamwork to forming learning communities yielded a one-factor solution explaining 82.09% of the variance and the reliability was 0.95 (KMO = 0.801, $c^2(6) = 808.38$, $p < 0.001$).

All the items of each section are available in the Appendix. All items, except those in which categories were indicated, were measured on a 5-point Likert scale ranging from 1 to 5. The values of asymmetry and kurtosis ranged, respectively between −0.66 and 0.02, and −1.29 and −0.72. These values are acceptable to prove normality in the item distributions (Byrne, 2010).

To ensure the validity of the different scales designed ad hoc for this investigation, exploratory factor analyses (EFA) were carried out. The unweighted least squares extraction method followed by a Promax rotation were used. Scales reliabilities were estimated using the McDonalds' omega statistic. Next, a descriptive analysis of the measured variables was conducted.

To compare the means of the variables considering the entire sample, the within-subjects repeated measures ANOVA technique (RM-ANOVA) was used. RM-ANOVA is the generalization of paired Students' t test. This technique is useful when the mean values in more than two traits of the same subjects are compared. Maulchy's

test was carried out prior to these analyses to study the sphericity assumption which was not met in any of the instances. For this reason, the degrees of freedom were corrected using the Greenhouse–Geisser approach. The effect size in RM-ANOVA was estimated using η^2, with reference values for interpretation: < 0.01 very small, 0.01–0.05 small, 0.06–0.13 moderate, and > 0.14 large (López-Martín & Ardura, 2023). Mean differences for comparing groups of independent subjects were carried out using the Student's t-test, with the effect size estimated using Cohen's d statistic. Reference values for the interpretation of the effect size in this case are: < 0.20 very small, 0.20–0.49 small, 0.50–0.79 moderate, and > 0.80 large (López-Martín & Ardura, 2023).

Students' decision making was investigated using Chi-squared Automatic Interaction Detector (CHAID). The CHAID segmentation technique is a statistical method used to identify and segment a population into distinct groups based on a set of predictor variables. It is a decision tree algorithm that analyses relationships between a target variable and several predictor variables to create segments with homogeneous characteristics. The algorithm constructs a decision tree by repeatedly splitting the data based on the predictor variable that provides the most significant separation between groups. Each branch of the tree corresponds to a segment, and the tree grows until no further significant splits can be made. In this study, the criterion variable was the students' prospective decision on the modality (individual/in teams) for the next assignment. Thus, CHAID allowed us to find the best predictors of the students' future intentions.

The data collection was conducted by means of an online survey following the completion of the course and after students had submitted their papers. Informed consent was obtained from all participants, and confidentiality and anonymity of participants were meticulously maintained throughout the data collection phase and subsequent analyses.

4 Empirical results

4.1 Students' perceptions of teamwork contributions to their education and what difficulties they anticipate

A RM-ANOVA was performed to compare the mean values of the students' perceptions of the contributions of teamwork to them (see Table 2). Significant mean differences were found, $F(6.61, 1931.58) = 18.28$, $p < 0.001$, $h^2 = 0.053$. Post hoc comparisons unveiled that, on average, students perceived the greatest benefits of teamwork to be associated with the enhancement of their communication skills (3.36), the facilitation of generating new knowledge (3.32), meeting educational needs (3.30), acquainting themselves with peers (3.27), mitigating isolation (3.24), and ultimately, fostering the creation of a learning community (3.23), without statistically significant mean differences among them. Nonetheless, these features, on average, significantly exceeded the perceived contributions of other factors presented to students (see Table 2).

When comparing students who worked individually with those who worked in a team, all potential contributions presented to the students in the survey demonstrated statistically significant differences, except for the enhancement of communication skills, acquaintance with classmates, establishment of a learning community, and mitigation of isolation (see Table 2). The remaining contributions exhibited statistically significant

Table 2 Students' perceptions regarding the contribution that teamwork can make for them

	Total		Team		Individual		Comparison		
	M	SD	M	SD	M	SD	t	p	d
MOTIVATION	2.95	1.36	3.13	1.37	2.53	1.26	3.51	< .01	0.44
PERFORMANCE	3.03	1.40	3.24	1.41	2.56	1.31	3.97	< .01	0.51
RESPONSIBILITY	3.14	1.30	3.35	1.3	2.66	1.31	3.99	< .01	0.51
INVOLVEMENT	3.06	1.36	3.30	1.37	2.53	1.21	4.58	< .01	0.58
COLLABORATION	3.32	1.30	3.44	1.34	3.06	1.17	2.35	.02	0.30
COMMUNICATION	3.36	1.32	3.42	1.35	3.21	1.24	1.28	.20	0.16
EFFICIENCY	2.85	1.38	3.10	1.40	2.27	1.16	4.97	< .01	0.63
GRADES	2.99	1.37	3.17	1.37	2.60	1.30	3.32	< .01	0.42
WORKLOAD	2.91	1.42	3.08	1.42	2.52	1.33	3.15	< .01	0.40
CLASSMATES	3.27	1.35	3.31	1.34	3.18	1.36	0.77	.45	0.10
COMMUNITY	3.23	1.30	3.32	1.30	3.03	1.30	1.74	.08	0.22
ISOLATION	3.24	1.39	3.29	1.41	3.12	1.35	0.95	.34	0.12
EDUCATION	3.30	1.25	3.53	1.23	2.78	1.14	4.94	< .01	0.62
TOTAL	3.13	1.11	3.28	1.14	2.77	0.96	3.74	< .01	0.47

MOTIVATION: Increase your motivation for the subject; PERFORMANCE: Improve your performance in the subject; RESPONSIBILITY: Take responsibility for your own learning; INVOLVEMENT: Increase your involvement with the subject; COLLABORATION: Collaborate to build useful and meaningful knowledge; COMMUNICATION: Develop your communication and knowledge transmission skills; EFFICIENCY: Perform the task more efficiently; GRADES: Improve my grade in the subject; WORKLOAD: Decrease the workload; CLASSMATES: Get to know my classmates; COMMUNITY: Create a learning community; ISOLATION: Reduce the isolation of distance learning; EDUCATION: Necessary for my education

variances between these two student groups, with effect sizes ranging from small to moderate.

One of the largest effect sizes in mean differences was found in students' perceptions of the indispensability of teamwork for their educational pursuits (d = 0.62). Furthermore, students who opted to work in a group believed that teamwork would enhance their efficiency (d = 0.63), increase their engagement (d = 0.58) and performance (d = 0.51), and foster a sense of responsibility (d = 0.51). Ultimately, they perceived that working in a team would bolster their motivation more than those who chose to work individually (d = 0.44) (see Table 2).

In Table 3, the average results of anticipated difficulties are presented for the total sample and disaggregated based on whether the student chose to work in a team or not. A RM-ANOVA was performed to compare the mean values of the students' anticipated difficulties when they tackle a teamwork activity and significant mean differences were found, $F(4.12, 1204.06) = 15.48$, $p < 0.001$, $h^2 = 0.050$. Even though the average values of each variable are rather similar, post hoc comparisons found that scheduling and availability difficulties, and member involvement were the main concerns of students regarding teamwork, being the challenges in communication the students' least concerns (see Table 3).

In Table 3, the group of students who worked individually are compared to those who work in a team, regarding their teamwork anticipated difficulties. Simple effects analyses showed statistically significant mean differences in all the anticipated difficulties except for the lack of prior knowledge about team members, being the average values of the rest of the difficulties higher in the case of students who worked individually. From a practical point of view, the lack of knowledge among team

Table 3 Anticipated difficulties for students regarding teamwork

	Total		Team		Individual		Comparison		
	M	SD	M	SD	M	SD	t	p	d
TEAM KNOWLEDGE	3.36	1.41	3.30	1.42	3.50	1.37	1.13	.26	0.14
AGENDA	3.80	1.24	3.69	1.27	4.04	1.16	2.29	.02	0.29
SOLO	3.56	1.35	3.43	1.39	3.86	1.20	2.51	.01	0.32
ADVANTAGE	3.52	1.39	3.41	1.44	3.78	1.22	2.10	.04	0.27
COMMUNICATION	3.13	1.35	2.99	1.37	3.44	1.26	2.70	< .01	0.34
PARTICIPATION	3.29	1.32	3.14	1.38	3.70	1.13	2.84	< .01	0.36
COMMITMENT	3.36	1.40	3.21	1.45	3.70	1.22	2.79	< .01	0.35
TOTAL	3.43	1.10	3.31	1.14	3.70	0.95	2.87	< .01	.36

TEAM KNOWLEDGE: Pre-existing lack of knowledge about team members; AGENDA: Agenda and availability difficulties; SOLO: Involvement of the members: "Some go their own way."; ADVANTAGE: Involvement of the members: "Some take advantage of the work of others."; REMOTE: Difficulties in remote communication; PARTICIPATION: Lack of participation in meetings; COMMITMENT: Lack of commitment

Table 4 Students' perceptions regarding the acquisition of skills

	Total		Team		Individual		Comparison		
	M	SD	M	SD	M	SD	t	p	d
INTERPERSONAL	3.32	1.28	3.32	1.35	3.33	1.11	0.08	.94	0.01
CONFLICT	3.19	1.27	3.20	1.34	3.16	1.12	0.29	.77	0.04
NEGOTIATION	3.27	1.26	3.28	1.32	3.26	1.12	0.13	.90	0.02
ACTIVE	3.33	1.30	3.40	1.36	3.17	1.14	1.45	.15	0.18
COMMUNICATION	3.16	1.31	3.17	1.36	3.13	1.19	0.21	.84	0.03
THINKING	3.33	1.27	3.33	1.32	3.33	1.16	0.02	.98	< .01
ADAPTABILITY	3.31	1.30	3.35	1.35	3.22	1.19	0.80	.42	0.10
EMPLOYABILITY	3.37	1.25	3.54	1.25	2.98	1.16	3.65	< .01	0.46
TOTAL	3.30	1.14	3.34	1.21	3.20	0.97	0.99	.324	0.13

INTERPERSONAL: Generate/Develop interpersonal skills; CONFLICT: Facilitate conflict resolution; NEGOTIATION: Generate/Develop negotiation skills; ACTIVE: Foster active learning; COMMUNICATION: Improve oral communication; THINKING: Promote critical thinking; ADAPTABILITY: Improve adaptability; EMPLOYABILITY: foster employability-oriented skills

members do not seem to be a problem regardless the modality chosen (d = 0.14). Besides, the largest effect sizes were related to the challenges in remote communication (d = 0.34), and the lack of commitment (d = 0.35) and participation in meetings (d = 0.36) (see Table 3).

Finally, Table 4 collects the students' perceptions about the skills they acquire when they work collaboratively. According to the students' perceptions, all the skills investigated were similar and ranged from 3.16 to 3.37. However, RM-ANOVA found statistically significant mean differences ($F(4.12, 1204.06) = 2.77$, $p < 0.001$, $h^2 = 0.009$). Post hoc analyses found that according to students' perceptions, the average in interpersonal skills was statistically higher than conflict resolution skills and oral communication. The two-group mean comparison only found significant differences in the case of skills related to employability which were higher in the group of students who chose teamwork. It is interesting to note than only the potential of teamwork to foster employability-oriented skills showed a moderate effect size (d = 0.48).

4.2 Students' choice of the working modality in the assignment

Figure 1 displays the CHAID decision tree. The criterion variable was whether the student chose the teamwork or the individual option. All the variables that showed significant mean differences across the two groups were introduced in the analysis as predictors of the students' choice, along with the work-wise situation and obligations that limit their study time. The model classifies correctly 72.1% of the total of students in the sample. Besides, the correct classification of students who chose to work in teams and who preferred to work individually was 72.6% and 71.1% respectively.

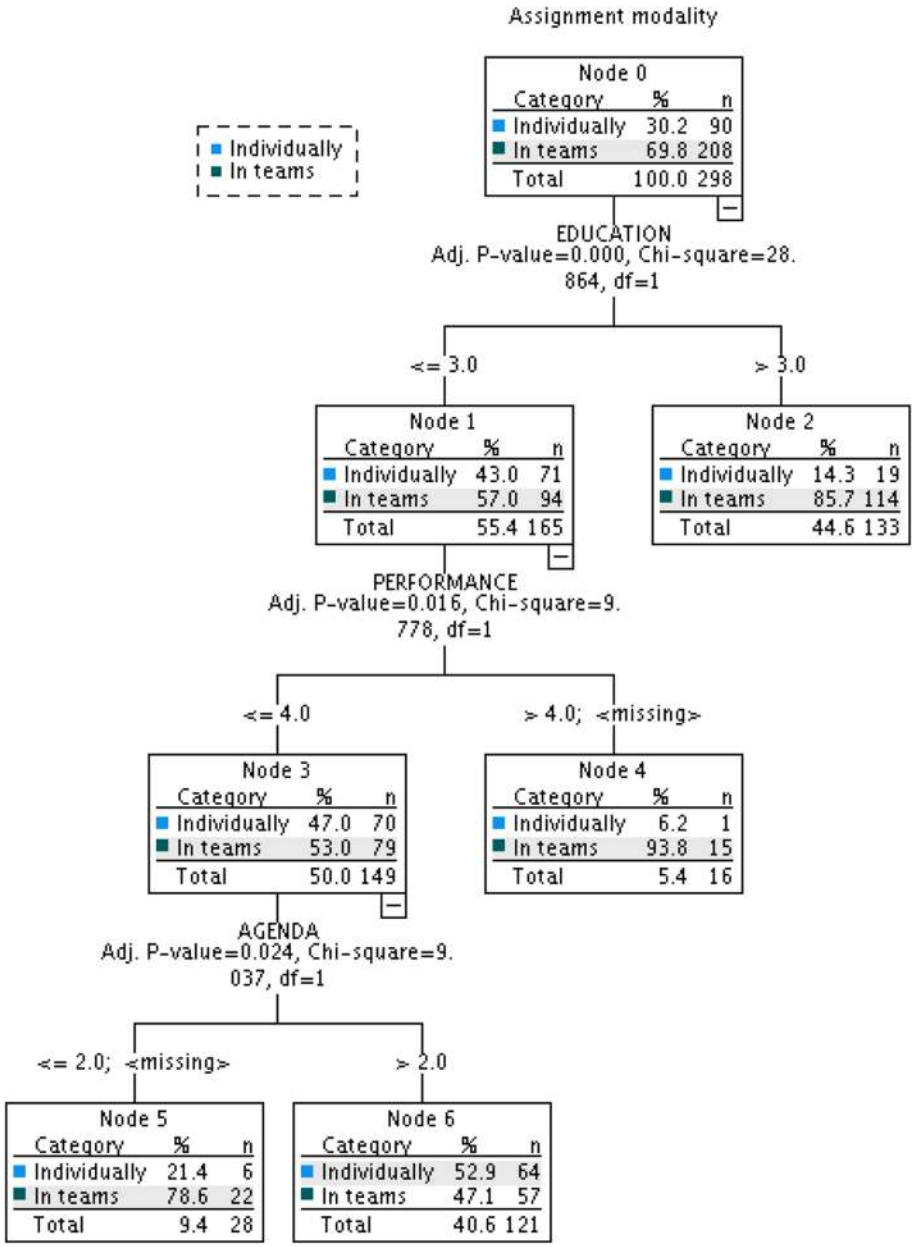

Fig. 1 CHAID decision tree for the criterion variable: assignment modality chosen by the student (individual or teamwork). EDUCATION: Necessary for my education; PERFORMANCE: Improve your performance in the subject; AGENDA: Agenda and availability difficulties

In view of the decision tree, the best predictor of teamwork selection was the perceived need of the students for their education. According to the decision tree, it is more likely that students scoring more than three on this item will choose to work in a team. Among students who perceive teamwork as less crucial for their education, those aiming to enhance their performance were more likely to opt for group work. Conversely, within the subset of students not prioritizing performance improvement through teamwork, those with fewer scheduling constraints and greater availability were more prone to choose this modality. Thus, the decision tree diagram suggests that students who prefer individual work generally do not perceive collaborative tasks as essential for their education, do not prioritize performance enhancement through teamwork, and face limited scheduling availability.

4.3 Students' perceptions of the aspects of teamwork requiring greater effort from them

During data collection, students working in teams were surveyed using a 5-point Likert-type scale to determine their preference for completing future assignments in teams or individually. Based on their responses, students were categorized into two groups: those scoring 4 or 5, indicating a preference for teamwork in future assignments ($n = 95$), and those scoring 1 or 2, indicating a preference for individual work ($n = 67$).

Significant mean differences were detected through a repeated measures analysis of variance (RM-ANOVA) comparing the mean values of students' perceptions of teamwork contributions (see Table 5). The analysis yielded $F(4.85, 775.31) = 4.28$, $p < 0.001$, with an effect size of $\eta^2 = 0.026$. Post hoc pair-wise comparisons revealed no statistically significant differences except for leadership, which had the lowest average score among all aspects surveyed (see Table 5).

Regarding the comparison between students willing to work in teams for future papers and those preferring individual work, although average scores were higher

Table 5 Students' perceptions regarding the aspects that have entailed greater effort during teamwork, disaggregated by students' willingness to use teamwork for future assignments

	Total		Individually		Teamwork again		Comparison		
	M	SD	M	SD	M	SD	t	p	d
MEETING	3.08	1.48	3.19	1.42	3.00	1.52	0.82	.41	0.13
LEADERSHIP	2.71	1.31	2.93	1.42	2.56	1.21	1.77	.08	0.28
DISTRIBUTION	3.14	1.35	3.48	1.33	2.89	1.14	2.76	< .01	0.44
FEEDBACK	3.02	1.43	3.22	1.43	2.88	1.41	1.50	.14	0.24
TRUST	2.94	1.43	3.24	1.44	2.73	1.40	2.28	.02	0.36
STEPS	3.10	1.32	3.21	1.37	3.02	1.28	0.90	.37	0.14
GOAL	3.01	1.39	3.18	1.38	2.89	1.40	1.28	.20	0.21
STYLE	3.15	1.39	3.30	1.45	3.05	1.35	1.11	.27	0.18
TOTAL	2.98	1.07	3.22	1.14	2.88	1.11	1.90	.06	0.30

MEETING: Kick-off of the first meeting; LEADERSHIP: Manage team leadership; DISTRIBUTION: Cooperation/Collaboration/Independent work; FEEDBACK: Feedback among teammates; TRUST: Trust and internal communication; STEPS: Accomplishment of intermediate steps; GOAL: Setting up a team common goal; STYLE: Homogenize the style and paper structure

among those favoring teamwork, only two aspects showed statistically significant differences with small effect sizes: workload distribution (d = 0.44) and internal communication and trust (d = 0.36).

4.4 Students' perceptions of the extent to which teamwork helps in building learning communities in hybrid education

A repeated measures analysis of variance (RM-ANOVA) was conducted to compare the mean values of students' perceptions regarding the contributions of teamwork (see Table 6). Significant mean differences were observed, $F(2.87, 460.56) = 2.88$, $p < 0.001$, with an effect size of $\eta^2 = 0.013$. Post hoc pair-wise comparisons indicated no statistically significant differences between the mean values of any pair of the four variables (see Table 6). However, when comparing students who would choose the teamwork modality for future papers with those who would prefer to work individually, statistically significant differences emerged between the two groups, with all effect sizes being large. According to students' perceptions, the most substantial effect size was associated with the belief that teamwork facilitated assistance among peers and mutual benefit (d = 2.46).

4.5 Students' intentions regarding the prospective modality for future assignments after having chosen teamwork this time

Figure 2 illustrates the CHAID decision tree regarding students' decisions regarding teamwork or individual work on future papers. All variables demonstrating significant mean differences across the two groups were included as predictors of students' choices. The model accurately classifies 91.4% of the total student sample. Furthermore, the correct classification rates for students intending to use teamwork in future papers and those preferring individual work were 83.6% and 93.8%, respectively.

The most significant predictor of students' future engagement in teamwork was their valuation of the opportunity to assist peers and receive assistance from them (see Fig. 2). Students who value this aspect with a score exceeding three points are more likely to opt

Table 6 Students' perceptions of the extent to which teamwork has contributed to building a learning community, disaggregated by students' willingness to use teamwork for future assignments

	Total		Individually		Teamwork again		Comparison		
	M	SD	M	SD	M	SD	t	p	d
INTERACTION	3.32	1.34	2.15	1.12	4.15	0.96	−12.21	< .01	1.94
PARTICIPATION	3.26	1.37	2.01	1.07	4.15	0.96	−13.33	< .01	2.13
HELP	3.43	1.36	2.12	1.05	4.36	0.80	−15.40	< .01	2.46
CONECTEDNESS	3.22	1.47	2.03	1.06	4.21	0.90	−14.13	< .01	2.25
TOTAL	3.33	1.27	4.22	0.70	2.07	0.90	−16.01	< .01	2.55

INTERACTION: Promoting and increasing interaction among peers; PARTICIPATION: Enhancing participation in the subject; HELP: Assisting peers and benefiting from the resulting feedback; CONECTEDNESS: Decreasing student isolation in semi-presential teachings

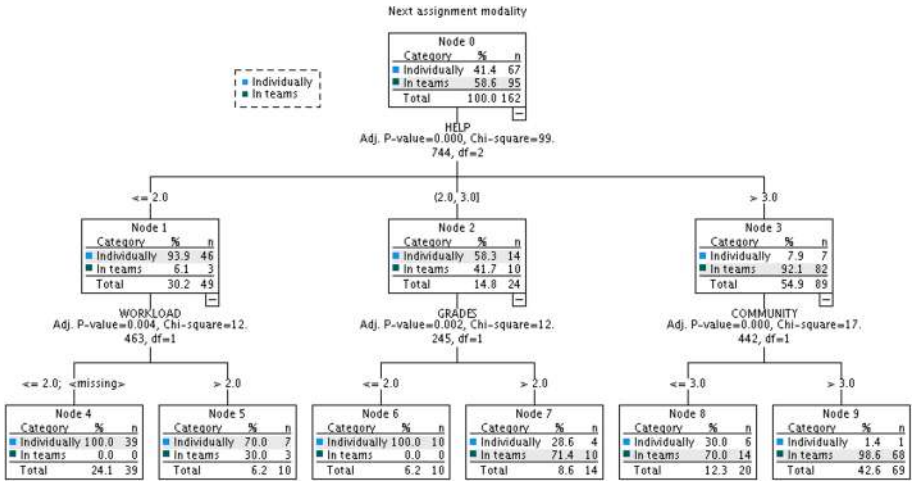

Fig. 2 CHAID decision tree for the criterion variable: assignment modality chosen by the student (individual or in teams) for the next paper after having chosen to work in teams on the present paper. WORKLOAD: Decrease the workload; GRADES: Improve my grade in the subject; COMMUNITY: Create a learning community; HELP: Assisting peers and benefiting from the resulting feedback

for team-based modalities repeatedly. Moreover, this likelihood increases among students demonstrating an interest in establishing learning communities. Among students with intermediate interest in offering and receiving assistance, the decision to engage in team-based work is notably influenced by their pursuit of enhancing subject grades. Ultimately, students with low motivation to assist and be assisted have minimal probabilities of persisting in team-based modalities and tend towards individual work. However, within this latter group, the probability of opting for teamwork increases if students perceive that this choice would alleviate their workload.

5 Discussion and conclusions

Promoting student involvement to achieve more complete and lasting learning via "learning by doing" ultimately responds to constructivist postulates, which place the focus on the student and his or her relevant role in the generation of his or her own knowledge and learning. This student involvement is especially important in hybrid education environments where student motivation and self-regulation are key factors for the success of the educational experience.

The role that students' perceptions of the indispensability of teamwork for their educational pursuits have in the results is noteworthy. Interestingly, the effect sizes indicated that both instrumental, such as perception such as task efficiency, and intrinsic oriented perceptions, as students' perception of the necessity of teamwork for their education, are relevant from a practical point of view. Moreover, students who opted to work in a group believed that teamwork would enhance their efficiency, increase their engagement and performance, and foster a sense of responsibility. Ultimately, they perceived that working in a team would bolster their motivation more than those who chose to work individually. Additionally, it is observed that students who prefer individual work generally do not perceive collaborative tasks as essential for their education, do not prioritize performance enhancement through teamwork, and face limited scheduling availability.

These results align with what was observed by Volkov and Volkov (2015) when considering that there is a group of students who perceive the team as a means to advance their individual and collective knowledge (compared to another group that only aims to solve it effectively).

Those students who value that carrying out the teamwork is necessary for their education opt for this activity. Among them, those who think that teamwork allows them to develop interpersonal skills are more likely to opt for it. The improvement of communication skills and the drive to generate knowledge are some of the main perceived benefits of teamwork, but interpersonal benefits are also noted, such as acquainting with peers, helping them and receiving help, reducing isolation, and ultimately, promoting the creation of a learning community. This result is in line with Ruiz Ulloa et al. (2004) since students recognize that the teamwork´s experience improves their interpersonal skills. In fact, the best predictor of returning to teamwork was the positive assessment of helping other colleagues and receiving help, as Pang et al. (2011) already pointed out. Among those students who do not consider the mutual help that facilitates teamwork to be especially important, other variables of a more practical nature, such as reducing workload or improving their grade, are also secondary predictors of the desire to repeat teamwork.

Employability also appears as an important factor for those who prefer teamwork with a moderate size effect, indicating the interest in equipping themselves with the necessary skills for the professional future. As Eitel (2018) points out, successful teamwork on university projects can contribute to the development of future professional skills in the workplace. Interestingly, the rest of the students' perceptions of acquisition of skills displayed low effect sizes and no significant mean differences were found when the two groups of students were compared.

On the negative side, practical aspects usually appear provoked by the distance or flexibility for the student of these types of teaching. The lowest perception about teamwork is effectiveness. Thus, scheduling and availability difficulties arise, along with challenges in remote communication, and the lack of commitment and participation in meetings. In fact, previous studies have shown that there is a relationship between satisfaction with teamwork and the time spent in class on that type of work (Oakley et al., 2007; Pfaff & Huddleston, 2003). However, in a hybrid environment, such as the one used for our research, it is much more complicated to dedicate time to teamwork in face-to-face sessions since many of the students cannot attend due to different incompatibilities. Moreover, the largest effect sizes in the students' perceived difficulties of teamwork when subjects who chose to work in groups were compared with those who completed the task individually are related to problems regarding in-group communication, participation, and commitment. Therefore, it can be posited that teammate trust is a relevant factor in explaining students' choice. Considering the outcomes of our study, it would be beneficial to implement preparatory measures prior to the commencement of teamwork. Such measures could facilitate enhanced interpersonal familiarity among students and foster confidence in their peers.

Additionally, the decision tree diagram suggests that students who prefer individual work generally do not perceive collaborative tasks as essential for their education, do not prioritize performance enhancement through teamwork, and face limited scheduling

availability. Coinciding with previous results in the literature, those who select individual work show greater distrust towards their colleagues, on the part of those who do it individually, confirming fear of free rider phenomena, as one of the most frequent drawbacks in line with previous research (Roberts & McInnerney, 2007; Chang, & Kang, 2016). In this sense, the results are aligned with Wolfe et al. (2016) who found as the first difficulty to encounter colleagues in the team who do not put enough effort. In fact, lack of communication and low individual responsibility were negative factors in teamwork experiences (Tseng & Yeh, 2013). Moreover, Ptaff and Huddleston (2003) find that the absence of people on the team who go "on their own" is one of the factors that predicts a positive attitude of students towards teamwork.

Our results suggest that perceptions related to the possible relationship between teamwork and the formation of learning communities (interaction, participation, mutual help, and connectivity) depend largely on students' satisfaction with teamwork. Indeed, it is those students who would do future teamwork display much higher levels of these perceptions. Furthermore, among students who show a high average level in the variable related to mutual help, the possibility of teamwork to create learning communities seems particularly important. These results are in line with Tseng and Yeh (2013) who showed how students who enjoyed working in groups had good relationships and trust with their team members. Likewise, this finding contributes evidence to that already detailed in the literature, indicating that, when the condition of student satisfaction is met, collaborative tasks contribute to the consolidation of learning communities (Slattery & Cleary, 2017).

5.1 Conclusions and future research

In summary, it is observed that those future educators who are more fully committed to their own learning and the development of their competencies tend to opt for teamwork. In contrast, future educators who focus on the potential drawbacks of teamwork, either because of difficulties in participating or distrust of their peers, tend to prefer individual work.

In this sense, we concur with the findings of Morgan-Thomas and Dudau (2019) in the context of online learning environments. In such settings, students tend to engage in activities that they perceive as most relevant or valuable for their learning. It is therefore essential to ensure that these activities are both useful and valuable (Naujokaitienė et al, 2020). It is evident that not all students, future teachers, are prone to teamwork a priori and therefore an effort of awareness and training to revert this effect is required. As Riebe et al. (2016) indicate, many educators may not have received any formal training in teaching methods or are not familiar with resources or collaborative approaches to develop students' teamwork skills. Moreover, as these same authors point out for some educators, it is not always clear how they should teach teamwork skills and it also implies an additional effort, namely transaction costs. It is clear that this awareness and training effort should be more intense with "future educators" who prefer individual work to avoid difficulties. This is especially important when it comes to technology integration into the classroom where the teacher's role becomes fundamental (Cabero-Almenara, Roig-Vila & Mengual-Andres, 2017). As Guri-Rosenblit (2018) indicates, the little attention paid to the crucial role of teachers

in online settings results in a restricted and moderate adaptation of the technologies in higher education worldwide.

Inadequate preparation can provoke or intensify negative perceptions of teamwork among students (Tombaugh & Mayfield, 2014). The future teacher must learn to establish a climate that encourages the active participation of students, the consensus of norms that facilitate the internal dynamics of the team and the definition of roles and schedules, as pointed out by Jaca et al. (2016). It is a path that he/she must travel from his/her own training. In addition, future educators must learn not to intervene excessively in the teams' internal dynamics when solving problems that may arise (Natoli, Jackling, & Seelanatha. 2014) and advance in cooperative learning dynamics (Liebech-Lien, 2021), not purely as from regular group work, but by working on social skills.

If effective teamwork is to be one of the objectives of the assignment, direct and detailed instructions are required on how to do it and how to solve the problems associated with such teamwork. These training instructions are required as part of the assignment itself. Teachers should introduce the concept of teamwork and how to best function in its implementation. Teachers can encourage future teachers to read about the topic, successful experiences and ideas that work, encouraging them to define teamwork to be carried out in the future. Initial team training sessions can be a good way to explain what is expected of participants, while also introducing elements of motivation. In addition, designing good teaching materials for collaborative learning is a demanding task for instructors, especially for teacher training. It requires offering the best conceptual materials while providing enjoyable team learning opportunities that can engage teams in working together for the entire duration of the class, as already indicated by Gomez et al. (2009). Future teachers should be taught to engage students through peer evaluation and to delve deeper into the process of evaluating and grading the work: process can be evaluated using a variety of measures, such as meeting minutes, peer and self-evaluations, students' email and chat exchanges, and progress reports. Definitively, teachers can help future teachers to develop the metacognitive skills they will need to succeed as future teachers of teamwork activities.

Certainly, further research is needed to build real communities of learning through teamwork, mitigating isolation, understanding which team assignments are more appropriate in these blended environments, and engaging the future educators to be trained to promote teamwork with their own future students. In particular, given that one of the aspects to improve in distance teaching is the reduction of students' feelings of isolation as Rasheed et al. (2020) suggest, continuing to work on how to use teamwork appropriately to reduce this feeling may be a promising line of future research.

In any case, we consider that the combination of teamwork with blended learning and perception of future educators intersects several interesting lines of research that, when connected, open interesting avenues for the future of education. Therefore, we consider that our humble findings can be an interesting contribution to continue exploring different strategies that help create robust learning communities in hybrid teaching, and

particularly in the training of future educators, an aspect that is perhaps the most original compared to other investigations.

Appendix. Survey items

Block I. Demographic and classification variables

1. Age
2. Gender (male, female, other/prefer not to answer)
3. Employment (Full-time, Part-time, Not employed)
4. Obligations limiting study time (Work, caregiving responsibilities, both, none)
5. I completed the paper (individual, team)

Block II. Impressions about teamwork from all students in the sample

Thinking about your experience while completing a team assignment, please answer the following questions:

6. In relation to teamwork, indicate to what extent it has been useful for you to:

Increase your motivation for the subject
Improve your performance in the subject
Take responsibility for your own learning
Increase your involvement with the subject
Collaborate to build useful and meaningful knowledge
Develop your communication and knowledge transmission skills
Perform the task more efficiently
Improve my grade in the subject
Decrease the workload
Get to know my classmates
Create a learning community
Reduce the isolation of distance learning
I consider teamwork tasks necessary for my education

7. To what extent do you consider that carrying out teamwork can be hindered by the following reasons:

Pre-existing lack of knowledge about team members
Agenda and availability difficulties
Involvement of the members: "Some go their own way."
Involvement of the members: "Some take advantage of the work of others."
Difficulties in remote communication.
Lack of participation in meetings.

Lack of commitment.

8. Regarding the competencies and skills acquired through the completion of the task, assess to what extent it has allowed you to:

Generate/Develop interpersonal skills
Facilitate conflict resolution
Generate/Develop negotiation skills
Foster active learning
Improve oral communication
Promote critical thinking
Improve adaptability
Foster employability-oriented skills.

Block III. Impressions about teamwork from individuals who chose to work in teams

9. What stages of the activity required the most effort and/or time?

Kick-off of the first meeting
Leadership
Cooperation/Collaboration/Independent work
Constructive feedback among participants
Trust and internal communication
Completion of intermediate stages
Unification towards a common goal
Standardization of work styles and structures

10. To what extent do you consider that this proposed teamwork contributes to forming Learning Communities in the following aspects:

Promote and increase interaction with peers (classmates)
Increase participation in the subject/course
Assist peers and benefit from the resulting feedback
Reduce student isolation in semi-presential teachings

11. How likely would you be to participate again in team activities? (1-5)

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Authors' contributions
JN designed the experiment, conducted theoretical and bibliographical analysis, prepared the survey, and drafted the initial article. DA performed the statistical analysis and contributed to the writing of the manuscript. AG directed

the project, coordinated the survey, and performed supervision and revision of the manuscript. All authors read and approved the final manuscript.

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Data availability
Data will be openly available in open repositories, once the manuscript will be accepted.

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Ethics approval and consent to participate
Authors accept journal's ethics guidelines and consent to participate. Authors avoid misrepresenting research results which could damage the trust in the journal, accepting ethics requirements in accordance to the journal submission guidelines.

Consent for publication
The authors give consent for publication.

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The evolution sustainable development in higher education: A bibliometric analysis (2014-2024)

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Abstract Higher education (HE) has a very important role in practicing and disseminating issues on sustainable development (SD). In recent decades, universities have competed to implement sustainable development (SD) in their curricula and educational systems. The aim of this study is to assess, through a systematic mapping of scientific literature, the development of research on SD in HE. Using metadata extracted from Scopus, a bibliometric approach was used to map the research literature on SD in HE. In this study, 2834 documents published between 2014 and 2024 were collected from the Scopus database. Citations, co-authorship and co-occurrence were examined using VOSviewer software. Findings indicate that research literature on SD in HE is mainly published in Spain and most citations come from English authors. Sustainable development, higher education and sustainability are common themes in the articles. These findings will be valuable for future research to identify 8 potential research areas of clusters, and develop new issues on SD in HE. Practically, this study provides a relevant literature review on SD in HE that can be used by universities leaders, communities and policy makers to develop a better framework for implementation SD in HE continuously.

Keywords: sustainability, universities, scopus, mapping, VOSviewer

1. Introduction

Over the last five decades, ‘sustainable development’ has become a major agenda implemented nationally and globally as part of sustainability (Lehtoranta et al., 2011). The destruction of nature has become more significant as economic and social progress has taken place (Klemeš et al., 2012). For this reason, all countries are focusing on the 'sustainable development' agenda. Sustainable development means that development does not harm future generations and was introduced by Brutland in 1987. In 1992, Agenda 21 was launched in Rio de Janerio, Brazil, as a blueprint for 'sustainable development' (Spencer, 2021). It formulated integrated institutional policies and identified NGOs as key actors in sustainable development.

Sustainable development is defined as the responsibility to improve the well-being of people and ecosystems (Cole, 2003). Sustainable development requires the role of all stakeholders, especially universities as key actors in social initiatives. Universities are active agents of knowledge and community engagement in response to current and future environmental and social challenges (Velazquez et al., 2006).

Internationally, the 1972 Stockholm Conference formally called on education to play an important role in environmental control and protection (UNEP, 1972). Universities, as institutions of higher education, have a role in the management and socialization of the negative impacts of environmental degradation caused by economic and social activities. Universities implement their roles through teaching, research, partnerships and managing resources to achieve sustainable development.

Matten and Moon (2004) define sustainable development as development that aims at improving the quality of human life while balancing social, environmental, and economic goals and benefits. Education for sustainable development develops individual and collective knowledge, values and skills to enhance the quality of life (Abidin & Khelgha-Doost, 2008). A systematic and integrated multidimensional plan for sustainable development in higher education involves long-term thinking with educational goals. In other words, higher education must be able to apply the concept of sustainable development by combining local and global knowledge, by involving all faculty, students and staff in systematic change, and by creating a framework that can generate new solutions to existing challenges (Keoy et al., 2011).

The shift in focus of education at all levels towards the Sustainable Development Goals (SDGs) has been well received almost all over the world. There are two forms of university involvement in the SDG framework: first, as a means of learning to impart sustainable development values and competencies, including gender equality, human rights, global citizenship, non-violence and peace (SDG 4.7). Second, universities support the SDGs set out through research, community service and collaboration with third parties (McCowan, 2019). However, the goal for higher education and universities (SDG 4.3) is seen as too abstract, with no concrete outcomes yet. Nevertheless, this is one way universities can contribute to SDGs.

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The bibliometric analysis aims to provide a map of SD research in universities by identifying publication trends, leading authors, institutions and countries/regions, collaborative networks between authors, countries/regions and institutions, disciplines that form the basis of SD research in universities, and keywords related to SD research in universities. For ease of understanding, separate tables and figures are provided for the various items. The result will be valuable in developing new sustainable development topics in higher education in existing research areas, or in developing existing topics in new research areas.

These findings have the specific goal of answering the research questions below:

RQ1: What are the publication trends on SD in HE?
RQ2: Who are the leading authors, Institutions and countries on the topic of SD in HE?
RQ3: How is the collaborative network between authors and countries on the topic SD in HE?
RQ4: What are the general themes of research on SD in HE ?

2. Materials and Methods

This study used bibliometrics to map the research literature on sustainable development implementation in higher education using Scopus metadata extracted from Elsevier. Bibliometric assessment can strengthen the principle of integrity in the publication process and increase the sharing of original research (Gureyev & Mazov, 2022), thereby reducing issues related to publication ethics. Two major bibliographic databases are Web of Science (WoS) and Scopus. As a representative data source for various purposes (Pranckutė, 2021; Zhu & Liu, 2020), Scopus has over the years gained a reputation as a comprehensive source of bibliographic data, proving to be reliable and in some cases superior to WoS (Harzing & Alaangas, 2015; Pranckutė, 2021). In this study, a three-step method was implemented by the researchers. It is presented in Figure 1 below.

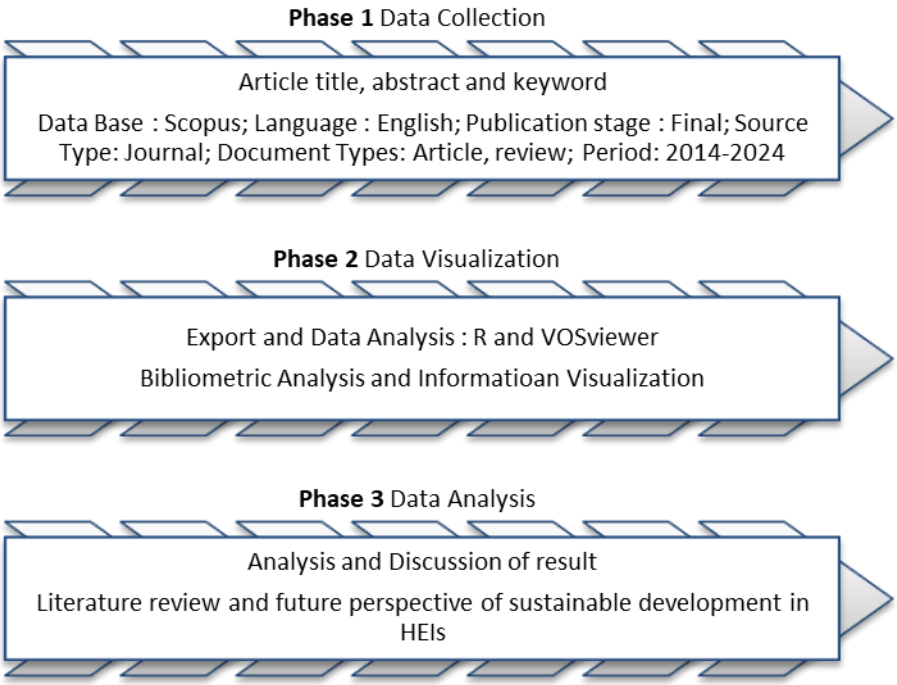

Figure 1 The methodology phases of constructing bibliometric analysis.

2.1. Data collection

In this phase, selecting the database is used to search for articles by defining the keywords according to the research (Ismawati & Churiyah, 2022). The Scopus.com database was searched for the dataset in the third week of April 2024. In order to create a representative corpus of documents for the research, four keywords were entered into the database: "sustainable development" OR "sustainable development" AND "higher education" OR "teaching". Subjects: social sciences (723), environmental sciences (514), agricultural and biological sciences (313), energy (285). Total number of citations 41777, total number of documents 2834.

In order to keep the results in line with the focus of the research, the key terms are made as specific as possible to SD in HEIs. Data that do not fit the scope and are published outside Scopus are excluded from the analysis. By using selective search methods, it is hoped that this study will provide valuable implications for developing ways of implementing SD in higher education, and that it will provide a research map that can be used as a guide for future research.

2.2. Data visualization

This phase collects data in CSV format, checks journal articles for each component: page, volume, number, year of publication, etc., and researchers complete incomplete data. Data analysis is then carried out by grouping the articles by source, year of publication and publisher. Bibliometric analysis is used to analyse and visualise bibliometric networks using VOSviewer software because it can provide efficient analysis, visualization and research results (Van & Waltman, 2009). The visualization of the network; the overlay visualization and the density visualization are the results of the VOSviewer visualization (Van & Waltman, 2009).

2.3. Data analysis

VOSviewer can create maps of authors, publications or journals based on keyword maps (Hudha et al., 2020). In this study, network visualization is used to show data clusters and overlay visualization to identify publication years. In addition, the network of co-authors on SD in HE is shown using the results of this visualization. Co-citation analysis is used to examine disciplines in sustainable development research. Co-occurrence analysis is used to see common themes related SD in HE. The data from the analyses will be presented in the findings and discussions, supported by previous literature reviews, so that the results of this study can reflect the development of SD in HE, especially in the last 10 years, and provide an overview of development opportunities in the future.

3. Results

3.1. Implementation of sustainable development (SD) in higher education (HE)

Sustainable development (SD) implementation in higher education (HE) presents different forms of system integration (Boks & Diehl, 2006). A review of the system of SD implementation in HE was conducted by Lozano et al. (2013). Furthermore, universities are also implementing SD through academic leadership commitment, greenhouse and regional development (Lee et al., 2013; Dlouhá et al., 2013). In this process, Europe is a leader and indicator of activities (Karatzoglou, 2013), with 30% of the global south and 20% of the USSR having signed.

Over 1000 university leaders have committed themselves to supporting SD transformation by agreeing to promote education through the Declaration on Education (Clugston & Calder, 2007). Conversely, some universities still regard SD as a radical innovation (Lozano, 2006a). The implementation of innovations such as sustainable development will face difficulties when implemented at the organisational level compared to the individual level (Rogers, 1995). However, if the innovation is accepted by the organisation, it will be transferred to society as a whole (Lozano, 2013). Compared to the total number of universities (Boks & Diehl, 2006; Lozano, 2010), the number of universities that have implemented sustainable development is still relatively small. ESD is not fully adopted or integrated into curricula of all disciplines, schools and universities (Fien, 2002; Matten & Moon, 2004). History of initiating SD in HEIs is presented in Table 1.

For hundreds of years, universities were key agents of change and paradigm shifts, training policy makers and future leaders (Elton, 2003). However, universities tend to operate in a traditional way (Lozano et al., 2015). Creating a better future for the next generation is a challenge for higher education.

Among the factors that have been cited for universities' reluctance in this area are a lacking awareness (Davis et al., 2003), intimidation by faculty (Peet et al., 2004), and an overloaded syllabus (Cortese, 2003). Furthermore, implementing sustainable development is considered irrelevant to certain disciplines and there are few efforts to integrate sustainable development into university curricula (Lambrechts et al., 2009; Lozano, 2010).

3.2. Trends in publications on sustainable development in higher education

The implementation of SD in the higher education sector is an important goal. There are many problems and challenges in implementing SD in higher education. Researchers and academics have done a lot of research on implementing SD in higher education. Issues related to SD are of great interest and continue to grow. There are 2834 documents in the database, cited 4000 times annually. Figure 2 shows the dynamic growth of the number of publications and research sources on SD in HEIs from 2014-2024 (10 years). Generally, the number of publications on sustainable development in higher education has increased continuously since 2014. This indicates that the topic is becoming increasingly interesting for researchers to research and develop, as evidenced by the increasing number of publications.

Publication of sustainable development articles in higher education is widespread in journals, proceedings, books and lecture notes. Table 2 shows which journals have published the most. With a total of 581 documents, Sustainability (Switzerland) has the highest number of publications according to the dataset. The second most published journal is the International Journal of Sustainability in Higher Education with 295 documents. The Journal of Cleaner Production follows with 171 documents. Although there are a number of publications in other sources, this is not a very large number for this topic.

Table 1 History of initiating SD in HE.

Year	Event/Declaration	Countries	Topic
1972	Stockholm Declaration on the Human Environment	United Nations	Human Environment
	Conference on the Human Environment	Sweden	Human Environment
1975	The Belgrade Charter, Belgrade Conference on Environmental Education	Yugoslavia	Environmental Education
1977	Tbilisi Declaration, Intergovernmental Conference on Environmental Education	Georgia	Environmental Education
1987	"Our Common Future", The Brundtland Report		Environment
1990	Talloires Declaration	France	Sustainability and Environmental Literacy
1991	Halifax Declaration	Canada	Sustainable Development
1992	Rio Conference	Brazil	Science for Sustainable development
1992	Assosiation of University Leaders for a Sustainable future founded	USA	Sustainable future
1993	Kyoto Declaration	Japan	Climate Change
1993	Swansea Declaration	Wales	University for Sustainable development
1994	COPERNICUS University Charter	Geneva	Ten principles of action University for Sustainable development
1996	Ball State University Greening of the Campus conferences were in 1997, 1999, 2001, 2003, 2005, 2007, and 2009	Indiana	Greening Campus
1997	Thessaloniki Declaration	Greece	Sustainability encompasses
1999	Environmental Management for Sustainable Universities (EMSU	Sweden	Sustainable University
2000	Millennium Development Goals		The health of women and children, gender equality, education, the environment and global partnerships.
2000	The Earth Charter		sixteen principles that drive a global movement
2000	Global Higher Education for Sustainability Partnership (GHESP)		Higher Education for Sustainability
2001	Lüneburg Declaration	Germany	Higher Education for Sustainable Development
2002	World Summit on Sustainable Development	South Africa	Sustainable Development
2004	Declaration of Barcelona	Barcelona	Humanity
2005	Start of the UN Decade of Education for Sustainable Development (DESD)	United Nations	Sustainable Development
2009	Graz Declaration	Austria	Committing Universities to Sustainable Development
2009	Abuja Declaration	Nigeria	The role of higher education in Sustainable development
2009	Torino (Turin) Declaration	Italy	Sustainable and Responsible Development
2012	Rio +20 Initiative	Brazil	Higher Education Sustainability
2015	Sustainable Decelopment Goals (SDGs)	United Nations	The 2030 Agenda for Sustainable Development

Source: Adapted and updated from Lozano et al. (2013).

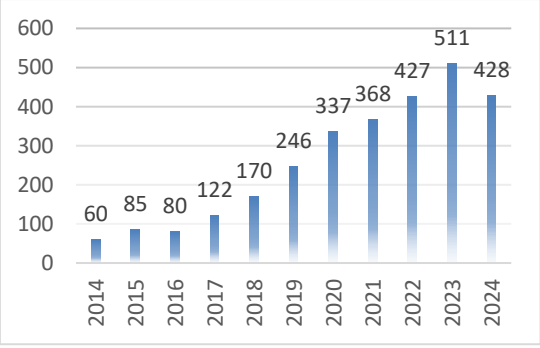

Figure 2 The Number of Publication on Sustainable Development in HEIs (2014-2024). *Source:* Scopus, 2024.

Table 2 Top Journal on Sustainable Development in HEIs.

Journal	Document
Sustainability (Switzerland)	581
International Journal of Sustainability in Higher Education	295
Journal of Cleaner Production	171
International Journal of Environmental Research and Public Health	33
Frontiers in Education	29
Environmental Education Research	25
International Journal of Management Education	25
Environment, Development and Sustainability	23
Education Sciences	22
Higher Education	22
Sustainable Development	20
Frontiers in Psychiatry	19
Journal of Teacher Education for Sustainability	16
Heliyon	15
Universidad y Sociedad	13
Frontiers in Sustainability	12
International Journal of Sustainable Development and World Ecology	12
PLoS ONE	12
Studies in Higher Education	12
GAIA - Ecological Perspectives for Science and Society	11

Number of publications does not always correspond to number of cited papers. Table 3 shows the top cited publications. The Journal of Cleaner Production is cited more than the Journal of Sustainability. The first position in the list is an article in the Journal of Cleaner Production entitled 'A Review of Commitment and Implementation of Sustainable Development in Higher Education' written by Lozano et al. (2015) with a total of 564 citations. The second position is an article in the Journal of Sustainability entitled 'Connecting Competencies and Pedagogical Approaches for Sustainable Development in Higher Education' Written by Lozano et al. (2017) with a total of 398 citations. In the top ten most influential publications, these two journals dominate the acquisition of the most citations.

Table 3 Most influential publications by number of citations.

Title	Journal	Year	Citation
'A review of commitment and implementation of sustainable development in higher education: Results from a worldwide survey'	Journal of Cleaner Production	2015	564
'Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal'	Sustainability (Switzerland)	2017	398
'Sustainable Development Goals and sustainability teaching at universities: Falling behind or getting ahead of the pack?'	Journal of Cleaner Production	2019	374
'Sustainability in higher education in the context of the un DESD: A review of learning and institutionalization processes'	Journal of Cleaner Production	2014	330
'Learning apart and together: Toward an integrated competence framework for sustainable entrepreneurship in higher education'	Journal of Cleaner Production	2014	316
'The role of transformation in learning and education for sustainability'	Journal of Cleaner Production	2018	305
'Key competencies in sustainability in higher education—toward an agreed-upon reference framework'	Sustainability Science	2020	290
'Conceptualization of sustainable higher education institutions, roles, barriers, and challenges for sustainability: An exploratory study in Portugal'	Journal of Cleaner Production	2018	273
'Competencies in education for sustainable development: Exploring the student teachers' views'	Sustainability (Switzerland)	2015	259
'Sustainable management of digital transformation in higher education: Global research trends'	Sustainability (Switzerland)	2020	256

3.3. Leading authors, institutions and countries

Table 4 shows the leading authors of the research on SD in HE. Leal Filho, with a total of 48 documents and a number of citations, has the highest number of article citations based on the dataset. In second place is Lozano with a total of 8 documents and a citation count of 1309. Although Lozano has few documents, he is cited a lot because each of his articles is successfully cited by many people. On the topic of SD in HE, the number of citations is very high, indicating that this topic is of great interest to many people and is a hot topic of discussion.

Table 4 Top authors by number of publications and citations.

No	Author	Documents	Citations
1	Leal filho, walter	48	2021
2	Lozano, rodrigo	8	1309
3	Brandli, Luciana londero	11	1079
4	Ceulemans, kim	5	985
5	Rieckmann, marco	12	928

On the other hand, research on SD in higher education is widely studied in different universities around the world. Manchester Metropolitan University in the UK has 16 documents with a total of 123 citations. The second leading institution in terms of publications and citations, with a total of 14 documents and 153 citations, is the Hamburg University of Applied Sciences in Germany. The top institutions are dominated by institutions from Europe and America. This indicates that research on sustainable development is widespread in these regions and that they focus on environmental and sustainability issues. The top institutions by number of publications and citations are shown in Table 5 below.

Table 5 Top institutions by number of publications and citations.

No.	Institution/Organization	Country	Documents	Citations
1	Manchester Metropolitan University	United Kingdom	16	123
2	Hamburg University of applied sciences	Germany	14	153
3	University of Passo Fundo	Brazil	8	80
4	University of Otago	New Zealand	6	114
5	State University of Campinas	Brazil	5	35

The countries with the most documents on SD in HEIs are listed below. Spain is the country with the most documents, totalling 389 articles. China (299), the United Kingdom (294) and the United States (236) follow. However, the United Kingdom was cited more (8356) than the other countries cited it (2623), which puts it in second place. The list of the top countries shows that all continents are represented: Europe, the Americas, Africa and Asia. Clearly, the whole world is interested in the implementation of SD in universities. The top countries by number of publications are shown in Table 6 below.

Table 6 Top countries by number of publications.

No.	Country	Documents	Citations
1	Spain	389	8250
2	China	299	2623
3	United Kingdom	294	8356
4	United States	236	5593
5	Germany	182	5099
6	Brazil	169	4060
7	Portugal	147	3552
8	Australia	134	2031
9	Malaysia	113	1264
10	South Africa	106	1681

3.4. Collaborative networks between authors and countries

A series of co-authorship analyses were carried out to identify networks of collaboration between authors and countries on SD. Unrelated articles were excluded from this analysis. Figure 3 shows the different relationships between authors. Each connected author means that each author has a relationship with others in conducting research on SD in HEIs. In accordance with Hernández-Torrano and Ibrayeva (2020), the more extensive the relationship between authors, the clearer the map and the clearer the lines of connection. The largest number of relationships was established by Leal Filho, Walter, with 48 documents and 38 links. In second place is Salvia, Amanda Lange with 22 documents and 30 links to other authors.The collaborative research between authors is shown in Figure 3 below.

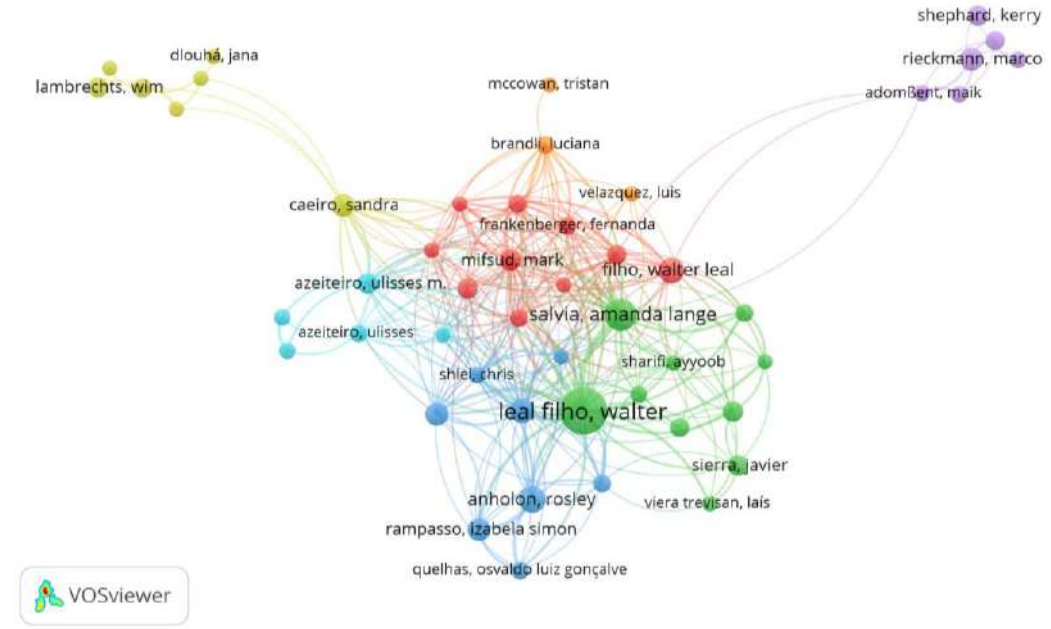

Figure 3 Collaborative research between authors.

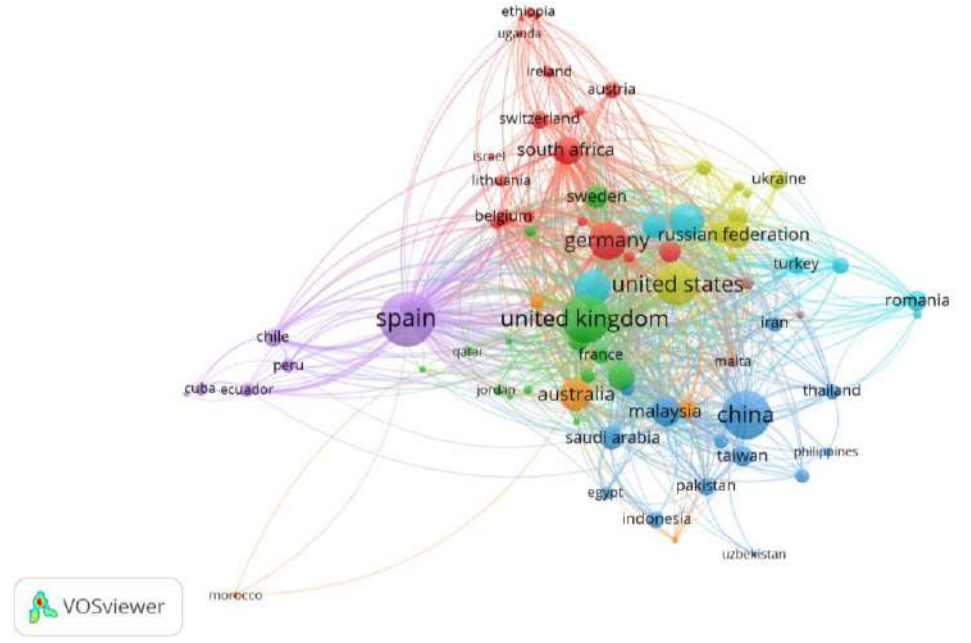

Figure 4 Collaborative research between countries.

80 countries were analysed in this study where there was a relationship in the co-authorship of at least 1 article. There are 8 clusters included in the dataset. Figure 4 shows that the dominant collaborations with other countries are with the United States, the United Kingdom, Spain, China and Germany. Brazil, Portugal and Malaysia have many networks with other countries. Meanwhile, other countries have collaborated in this study. Collaboration with other researchers is a strategy for disseminating research results (Martinez & Sá, 2019). It is clear from Figure 5 that this topic is very important and is applied in universities in many countries and is in line with current developments.

3.5. General themes of research on sustainable development in HE

According to Zhou (2022), co-occurrence analysis is used to identify potential relationships between two co-occurring bibliographies. This analysis shows that many clusters were developed in this study, indicating that there are many analysis topics related to SD in HE. An interesting aspect of this analysis is that keywords are taken from all documents' abstracts and keyword lists. The more terms found in a document, the closer the connection (Hernández-Torrano and Ibrayeva, 2020).

Common themes on sustainable development in university publications were identified using co-occurrence analysis. The number of occurrences of each keyword is represented by the size of each node in the map. Larger and clearer nodes indicate that the keyword is frequently used in publications and is a common theme that appears in the area. The general themes of research on sustainable development in higher education are shown in Figure 6 below.

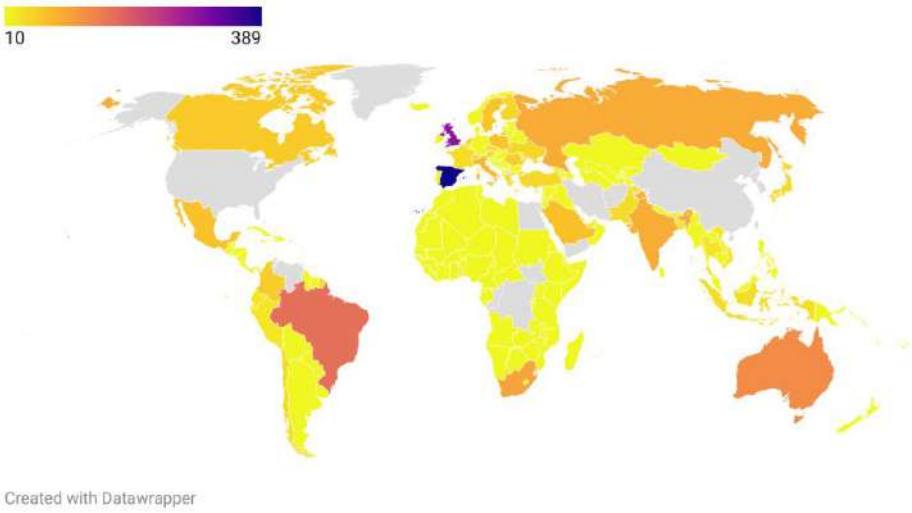

Figure 5 Geographical distribution of authors.

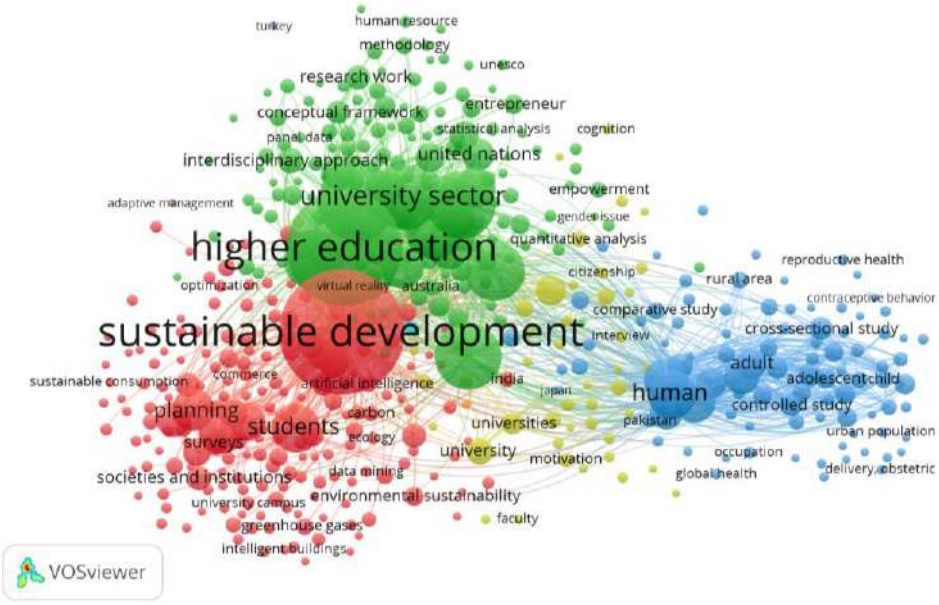

Figure 6 General themes of research on sustainable development in HE.

In the co-occurrence analysis based on the dataset, there are 8 clusters (n = 4449, met threshold = 483). The first cluster consists of 179 items that focus on discussing the application of SD in HEIs, including sustainable development, Sustainability, higher education, human, student, environment, planning societies and institutions. Cluster two shows the extension of higher education such as conceptual framework, research work, methodology, entrepreneur and university. Meanwhile, Cluster 3 highlights research on human issues such as rural area, urban area, cross-sectional study, poverty and motivation. The fourth cluster focuses on research on universities such as students, universities, faculty and covid 19. Cluster 6 has 2 keywords: Software and Turkey. Cluster 6 discusses 1 keyword: assessment method, cluster 7: switzerland and cluster 8 focuses on adaptive management. In the dataset, three large clusters show publications on SD in HEIs, including the application of SD in higher education (cluster 1), research in higher education (cluster 2) and research on people (cluster 3).

The evolution of SD research themes in higher education from 2014 to 2024 is shown in Figure 7. SD research in higher education is in a state of evolution. The application of SD in higher education started with the Stockholm Conference in 1972. Higher education continues to develop ideas on how to integrate SD into its curricula and systems. Various declarations have helped higher education to obtain guidelines for applying sustainable development (Lozano et al., 2013).

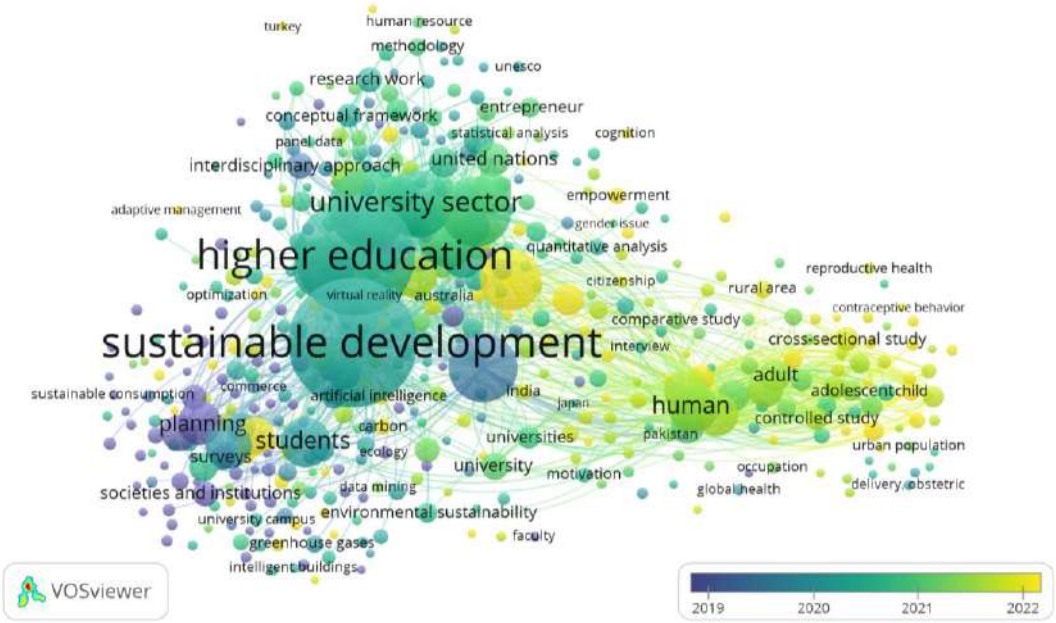

Figure 7 Evolution of research on sustainable development in HEIs.

In Figure 7, the purple bubble indicates the first year of research and the more yellow bubble indicates the latest research developments. At the beginning of its development, higher education focused on several things related to SD, such as planning, surveys and the relationship between societies and institutions. Then, in the middle years, the green bubble shows several research topics, namely sustainable development, higher education, university sector and students. While the yellow bubble generally describes the research theme that has shifted to variations of SD research methods in HE, including controlled studies, cross-sectional studies, human, urban, rural and cognition.

From the three developments of sustainable development research in HEIs it can be concluded that the evolution of research themes begins with planning, implementation and research development. Some themes are closely related and some still stand alone, so that in the future collaboration may take place on several related themes, but there is no link between them. In the future, it can be predicted that research related to SD in HEIs will continue to develop. Universities will continue to co-operate with Government, Environment and Industry. The common goal of protecting the environment makes it a common issue to be solved together.

To sum up, Based on Figure 8, the bibliometric results show that there are 40 most important keywords in research on SD in HEIs. It is identified based on the occurrence of "sustainable development" and "education" in the blue cluster 1, "sustainability", "higher", "university" in the blue cluster 2, "urban", "population", "environment" in the green cluster, "experiment", "citizenship", "adaptive" in the red cluster, "innovation", "knowledge", "planning" in the purple cluster, and "health", "sector", "comparative" in the black cluster.

Figure 8 Word cloud of the most frequent keywords related to sustainable development in HE.

4. Discussion

The issue of sustainable development was initially rejected by various universities around the world, but this was later reconsidered. They considered it to be a social discussion separate from the world of education. They also thought that integrating knowledge about sustainable development into the education curriculum would be difficult to implement. Nevertheless, the United Nations persisted in convening conferences and deliberations on sustainable development from 1972 onwards. The aim was to make all countries aware that sustainable development is a shared responsibility because it relates to environmental management. It is necessary to raise public awareness widely of the need to support education (Lozano, 2010).

This study is valuable in provides an overview of the publication trends of researchers, academics, and practitioners on sustainable development in higher education. The results show that the topic of sustainable development has become the focus of research and development, especially in higher education, as evidenced by the continuous increase in publications on the topic every year. This is in line with Lozano et al. (2015) research, which suggests that higher education institutions are already committed to implementing sustainable development. The number of citations for each article indicates its impact and inspires others to conduct similar research. Research on sustainable development is widely published in the journal Sustainability because sustainable development is essentially part of the discussion on sustainability.

Currently, the topic of Sustainable development in higher education has attracted many people and continues to be a topic that is developed and connected to all fields of research. Almost all countries in the world have contributed to conducting research on this topic. reviewing the importance of sustainable development in higher education, research collaboration between universities is needed. Collaboration from each country and researchers provides an illustration that they are strengthening their research results on the application of sustainable development in that country. Based on the research results, European countries initiated the application of sustainable development in higher education. Germany is a country that collaborates a lot with authors from other countries. This collaboration is carried out because researchers want to expand and disseminate their research results to other countries (Martinez & Sá, 2019).

The results of this study indicate that current research can be grouped into 8 clusters. On the basis of these clusters, several research topics can be proposed: teaching sustainable development (Wals, 2014; Lozano, 2019; Brundiers et al., 2020; Melati et al., 2023), implementing sustainable development in higher education (Hesselbarth & Schaltegger, 2014; Albareda et al., 2019; Beynaghi et al., 2016; 児玉弥生 & 三宅博之, 2018.), and collaboration between universities and industry in sustainable development (Purwadi et al., 2024; Meyer et al., 2017; Caniglia et al., 2018; Podgórska & Zdonek, 2023; Mariani et al.,2022).

Associated with sustainability, several previous studies have focused on greenhouses (Vásquez et al., 2015; Klein-Banai & Theis, 2013), gases (Hall & Vredenburg, 2003; Nhamo, 2019), the environment (Ramos et al., 2015; Leal et al., 2017; Mukhlis et al., 2022), waste management (Adeniran et al., 2017; Ferronato et al., 2018., Prastiwi et al., 2024), and people (Sedlacek, 2013; Sonetti, et al., 2019; Djatmika, 2016; Mukhlis, 2019, Sumarsono et al., 2016). Research on sustainability cannot be separated from the issue of environmental improvement, and many aspects can be studied. The direction of research development can be an extension of existing topics and can be combined with related topics. Aspects of sustainability include society, schools, industry and government. Improvements toward the realization of sustainable development goals will be affected by any supporting activity. This is in line with the research of Albareda-Tiana et al. (2019) related to the development of research on sustainability which is not only in the field of society but also in government policies and the implementation of the curriculum in schools. Many studies support the results of this study related to the role of government in making sustainable development a success (Beynaghi et al., 2016; Clugston & Calder, 2007).

The research methodology used in previous research on the topic of sustainable development in higher education includes: experimental (Peet et al., 2004), comparative (Ramos et al., 2015), cross-institutional (Caniglia et al., 2018; Dlouhá et al., 2013), quantitative (Klein-Banai & Theis, 2013), and RnD methods (Cole, 2003, Lozano, 2006). Various research methods can still be developed, such as action research, technological innovation, AI creation, and collaboration and dissemination among universities worldwide.

Related to the application in education, previous studies refer to curriculum design(Lozano & Young, 2013; Lozano et al., 2013; Cortese, 2003), Competences measurement (Lozano et al., 2017), interdisciplinary (Meyer et al., 2017; Podgórska, & Zdonek, 2023) , adaptive learning (Willies, 2023), and technology application (McCowan, 2019; Leal et al., 2019). The application of SD in higher education provides many opportunities for researchers to study different aspects both internally and externally to the university, both globally and nationally. This application involves all parties, teachers, students, the community and the role of policy makers.

The latest emerging issues should also be considered in future studies. In certain areas, the focus of future research can be directed toward solving management problems related to Sustainable Development, creating green entrepreneurship, using digitalization to transfer knowledge to society, and a joint curriculum framework with industry as a guide for policy makers. In general, it can be concluded that in addition to technical studies, further studies can be directed to various fields, especially economic and social fields, to increase program sustainability. Future studies are also expected to elaborate theories related

to community needs. Thus, a new paradigm is created in terms of awareness and new habits in society to support a green environment.

This study is limited by its reliance on bibliometric analysis, as no bibliometric results are perfect (Hernández-Torrano & Ibrayeva, 2020). Due to the large number of research sources, some search sources were excluded from this study. Therefore, further research could focus on more specific topics. Despite the limitations of the study, the results of this study can be believed to have representative results and can be used as a source of relevant literature studies on the topic of sustainable development, especially in higher education.

5. Final Considerations

The government's focus on the realization of the SDGs encouraged researchers to continue developing this research. Universities play a very important role in the successful implementation of sustainable development. Through universities, sustainable development can be transferred to the community. Universities also produce many methods and analyses that can be used to implement sustainable development. From the general theme of sustainable development in higher education, it can be seen that most of the published studies discuss best practices and challenges of implementing sustainable development in universities. The implementation of sustainable development in higher education is carried out through curriculum integration, industrial working practices and much research to overcome existing environmental problems. The challenge is how to involve and synergize higher education with the community, government and industry so that sustainable development goals can be properly achieved. In addition to trying to solve their own problems, each country has different problems related to sustainable development. However, collaboration between researchers and researchers from other countries also has a significant effect on solving problems. Therefore, cooperation between researchers is needed to increase the dissemination of research results.This study provides many opportunities for SDG-related studies, especially those on the contribution of higher education to sustainable development. Furthermore, environmental management can be accelerated and constrained by the implementation of Sustainable development in higher education.

Ethical Considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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The mechanism of academic self-efficacy in the relationship between professional identity and learning engagement among university students

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University students' learning engagement is related to the quality of talent cultivation in universities, which has an important impact on their academic performance and future development. In order to explore the influence of professional identity on university students' learning engagement and the mediating role of academic self-efficacy, the University Students' Professional Identity Questionnaire, the University Students' Academic Self-Efficacy Questionnaire, and the University Students' Learning Engagement Questionnaire were used to conduct questionnaire surveys and empirical analyses of 4,125 Chinese university students. Among them, professional identity was used as a predictor, academic self-efficacy as a mediating variable, and learning engagement as an outcome variable. SPSS 26 and PROCESS macro 3.5 were used to explore the mediating mechanism affecting university students' learning engagement. The findings of the study demonstrated the following: (1) All sub-dimensions of professional identity except affective professional identity showed a significant positive relationship on learning engagement; (2) Apart from two specific paths associated with the affective professional identity, the remaining sub-dimensions of professional identity exerted a positive partial mediating influence through the sub-dimension of academic self-efficacy; (3) The sub-dimensions of academic self-efficacy played a chain mediating role in the influence of the sub-dimensions of professional identity on learning engagement. This study enriches the understanding of the underlying mechanisms of the relationship between professional identity and learning engagement, thus providing valuable insights for university workers and related personnel seeking to enhance students' learning engagement in higher education.

Keywords University students, Professional identification, Academic self-efficacy, Learning engagement, Intermediary analysis model

Learning engagement is an evaluative indicator of student growth experiences as well as a predictor of quality in higher education[1]. University students learn more when they invest their energies in a variety of educationally purposeful activities[2]. An academic survey based on 311 undergraduate higher education institutions in China concluded that university students' learning engagement is an important predictor variable of academic success in college[3]. Many scholars hold similar views[4,5]. Learning engagement is a function of the time and energy that an individual invests in learning, focusing on the cognitive and affective[6]as well as behavioral and social factors[7]that an individual experiences while engaged in the process. It is the sum of the physical and mental energy that a student puts into the academic experience[8]. University students' learning engagement consists of three different behaviors: cognitive effort (the amount of time students spend on coursework), affective participation (students' participation in classroom questions, discussions, and project-based learning), and interactions with instructors (students' discussions of assignments or career plans with instructors)[9]. China College Student Survey (CCSS), the National Survey of Student Engagement (NSSE) in the United States, and the National Student Survey (NSS)

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in the United Kingdom reflect the importance that countries place on university students' learning engagement. University students' learning engagement has become a widespread concern in various countries. According to the latest statistics from the Ministry of Education of China, the total number of students enrolled in higher education is more than 58 million, of which 19,656,400 are enrolled in general undergraduate programs[10]. China has established the most extensive higher education system globally and remains steadfast in its commitment to fostering high-quality development within the sector of higher education[11]. However, the lack of investment in learning by Chinese university students has become a significant constraint on the transformation of China's higher education from "big" to "strong"[12]. In China, many parents attach great importance to their children's education. Education expenditure is an important part of household expenditure. Before students go to university, their studies are arranged tightly by parents and teachers, especially in senior high school. When it comes to university, students have more time at their disposal, but they may face the awkward dilemma of not knowing how to use their time wisely and how to learn properly. Therefore, this study focused on a group of Chinese university students and explored their learning engagement as China's higher education entered a phase of universalization. An experimental intervention study has shown that enhancing students' positive self-concept can significantly improve their learning engagement[13]. Self-concept constitutes a suite of attitudes that individuals possesses regarding themselves, encompassing cognitive and affective dimensions of self-perception, including an awareness and comprehension of one's own values, interests, competencies, and personality traits. It has emerged as a pivotal construct in elucidating human behavioral patterns[14]. Professional identity is the embodiment of self-concept in the professional domain. Based on the theory of professional identity, it has been suggested that students' cognition, feeling and commitment to their majors will affect their learning engagement behavior[15]. It has been confirmed that professional identity has a significant positive predictive effect on learning engagement[16–18]. In addition, according to Bandura's self-efficacy theory, students' self-efficacy has a significant impact on their classroom participation and learning persistence[19]. Existing researches have shown that academic self-efficacy significantly and positively predicts learning engagement[20–22]. Moreover, self-efficacy acts as an active precursor of self-concept development[23]. There may also be correlation between professional identity and academic self-efficacy. While prior research has frequently examined the relationship among these three dimensions without delving into their respective sub-dimensions, this study aims to investigate the interrelationships between the distinct sub-dimensions of professional identity and learning engagement, as well as to elucidate the mediating role of academic self-efficacy sub-dimensions within this dynamic process. Therefore, our research facilitates a more comprehensive, specific, and in-depth understanding of the influence mechanisms of Chinese university students' learning engagement.

The relationship between professional identity and learning engagement

Professional identity is a subjective feeling within an individual balanced with the profession[24]. It is a gradual, positive, and dynamic development process[25]. Professional identity is regarded as an emotional acceptance and recognition of learners' cognitive understanding of the profession they are studying, accompanied by positive external behaviors and an internal sense of fitness. It is divided into four dimensions: fit, behavioral, affective and cognitive. Fit professional identity reflects the degree of match between the individual and the profession; Behavioral professional identity reflects the individual's behavioral performance of professional learning; Affective professional identity reflects the extent to which an individual holds emotional preference for the profession, while cognitive professional identity indicates the degree to which they understand its basic aspects[26]. A number of studies have confirmed a significant positive correlation between professional identity and learning engagement[27–30]. A study of medical students has found that a higher sense of professional identity could foster confidence in their future roles as physicians and positively shapes their interactions with colleagues, professional groups and patients. It helps to promote the integration of students' selves with their career path and increases their learning engagement in their field, thus subsequently facilitating mature career decisions[31]. An analysis of the literature from 2019 to 2023 further reveals that students with a stronger alignment in professional identity are more likely to adopt tailored and personalized learning strategies to address academic challenges. These students also exhibit a greater tendency to pursue elevated standards of professional performance and engage in extracurricular activities that foster professional growth, thereby enhancing their overall level of academic engagement[32]. Cognitive professional identity and fit professional identity are positively correlated with learning engagement. Besides, students develop their professional values through interaction and collaboration with other students in the classroom. When the interaction process is good, it facilitates students' affective professional identity, promotes their self-development and increases their learning engagement[33]. In a large-scale study of 10,901 medical students across 11 universities in China, it has found that the higher the students' affective professional identity, the better it is for stimulating positive qualities such as optimism, resilience, sense of meaning and creativity, ultimately facilitating better performance[34]. These students are able to solve problems in the learning process with a relatively positive, fulfilling, and full mindset. They have a high level of concentration and are willing to put a corresponding amount of energy into learning and overcome difficulties[35]. A correlation also exists between affective professional identity and learning engagement. In addition, students with higher levels of professional identity tend to perceive tasks as variable, challenging, meaningful, and interesting. This positive perception fosters greater receptivity towards instructors, peers, and the academic environment. Consequently, these students demonstrate a greater propensity to employ deep learning strategies, investing the necessary cognitive effort to comprehend complex concepts, ultimately enhancing their focus and learning engagement[36]. Behavioral professional identity is also significantly and positively related to learning engagement. In summary, hypothesis H1 is proposed:

H1: Professional identity has a significant effect on learning engagement.

H1a: Fit professional identity has a significant effect on learning engagement.

H1b: Behavioral professional identity has a significant effect on learning engagement.

H1c: Affective professional identity has a significant effect on learning engagement.
H1d: Cognitive professional identity has a significant effect on learning engagement.

Mediating effects of academic self-efficacy

Academic self-efficacy refers to an individual's judgment and confidence in his or her ability to successfully complete academic tasks, and it is divided into two dimensions: academic competence self-efficacy and academic behavior self-efficacy. Academic competence self-efficacy refers to an individual's judgment and confidence in his or her ability to successfully complete school, achieve good grades, and avoid academic failure. Academic behavior self-efficacy, on the other hand, refers to an individual's judgment and confidence that he or she is able to adopt certain learning methods to achieve learning goals[37]. It has been found that students with a high sense of professional identity derive intrinsic motivation from the learning process, bolstering their confidence in confronting academic challenges and obstacles. Such students are able to positively predict individual behaviors and make changes to improve their overall competence[38]. Research conducted on tourism students has further demonstrated that enhancing students' awareness and comprehension of their professional prospects, coupled with guiding them to establish specific, actionable, and phased goals, can significantly improve their academic self-efficacy[39]. Professional identity is positively related to academic self-efficacy[40]. Besides, academic self-efficacy affects students' learning engagement[41–43]. A survey of second language learning has found that learning engagement is an important factor influencing students' second language proficiency, as well as one of the key outcomes of academic self-efficacy. As an important factor affecting students' psychological belonging and academic motivation, professional identity can further promote learning engagement by stimulating academic self-efficacy[44]. Academic self-efficacy plays a mediating role between professional identity and learning engagement. A study of 1,162 rural tuition-free medical students has found that students with a low sense of professional identity believed that "it is the same whether they study or do not study, and whether they study well or not". They tend to be pessimistic and disillusioned about the future, and are not willing to spend time and effort to complete their studies in their major at a high level, or even fulfill to their duties as interns during the internship period[45]. This group of students are less goal-oriented, tend to focus on things that could eventually go wrong, and often imagine failure scenarios that hinder their actual ability and undermine their performance, leading to poorer performance in their studies and lower levels of their learning engagement[46]. Academic competence self-efficacy may mediate the relationship between professional identity and learning engagement. Another study on students' self-directed learning has found that students with a low sense of professional identity exhibit diminished self-directed learning capabilities, struggling to personalize learning plans or effectively utilize resources. These students have low self-efficacy and lack the ability to effectively identify, analyze and synthesize information related to their learning needs. Consequently, they may find it difficult to derive pleasure and enrichment of taking in knowledge in the process of learning, which in turn leads to their avoidance of learning behaviors and their low level of learning engagement[47]. However, students with high professional identity can effectively grasp professional opportunities, identify and utilize objective development resources to effectively cope with learning tasks and academic challenges. They are willing to make efforts to improve their overall development skills[48]. For this reason, academic behavior self-efficacy may also play a mediating role between professional identity and learning engagement. In summary, hypothesis H2 is proposed:

H2: Academic self-efficacy mediates between professional identity and learning engagement.

H2a: Academic behavior self-efficacy mediates between the sub-dimensions of professional identity and learning engagement.

H2b: Academic competence self-efficacy mediates between the sub-dimensions of professional identity and learning engagement.

Chain-mediated effects of academic competence self-efficacy and academic behavior self-efficacy

Collaborative learning experiences and participation in professional learning communities can strengthen students' understanding of their chosen major, foster a stronger sense of professional identity, and sustainably stimulate their interest in learning, thus making them more willing to invest more time and effort in their majors[49]. Another study has a similar view. Students with a high sense of professional identity are able to take advantage of relevant opportunities, which helps them to have clearer and more feasible steps to implement in their future plans. These students are more engaged in their studies[50]. Conversely, practicing nurses with a low sense of professional identity may experience a compromise in their beliefs regarding professional development due to persistent exposure to stressors, work overload, or high job demands. This can diminish their academic self-efficacy, subsequently leading to reduced learning engagement[51]. It has been shown that professional identity is positively related to learning engagement and that learning self-efficacy plays a mediating role. Academic self-efficacy is a strong predictor of students' academic performance. Students with high academic self-efficacy have an active learning state. They are able to appreciate the physiological and psychological energy invested in the learning experience, and they are willing to put in the mental energy and effort to achieve the expected performance and continuously improve their overall competence[52]. There may also be a correlation between academic competence self-efficacy and academic behavior self-efficacy as two sub-dimensions of academic self-efficacy. A study of Romanian health care students during the COVID-19 pandemic has revealed that uncertainty regarding the pandemic's duration, fear of infection, and unfamiliarity with the nuances of online education and assessments contributed to a decline in students' self-confidence in their independent learning abilities, which resulted in a decline in all of their study skills owing to negligence in practicing to consolidate them. Their overall academic self-efficacy was low[53]. In a study of on-campus or online learning, it has found that students with high academic self-efficacy believe that they are able to monitor their own progress, control their learning resources (including the learning environment and study time), as well as regulate their own level

of effort. These students exhibit a strong belief in their capacity to intentionally implement positive behavioral interventions to enhance their learning. This involves actively monitoring, regulating, and controlling their cognitive, motivational, and learning behaviors, thereby promoting progress in their academic achievement to a greater extent[54]. In summary, hypothesis H3 is proposed:

H3: Academic competence self-efficacy and academic behavior self-efficacy play a chain mediating role between the sub-dimensions of professional identity and learning engagement.

This study constructs the parallel mediator model and chain mediator model to examine the influence of professional identity on learning engagement and the mediating role of academic self-efficacy between the two in a group of university students, with a view to providing guidance for improving the level of university students' learning engagement, and the theoretical conceptual model is shown in Figs. 1.

A parallel mediation model assumes that each mechanism is independent and separate, accounting for the unique and incremental effects of the independent variables on given dependent variables[55]. They are conceived as independent and separate pathways leading to the outcome variables. Relative to the parallel mediation model, according to Rosen et al. (2014), the sequential mediation model has the advantage of incorporating multiple theoretical mechanisms into a comprehensive and integrative model, thereby providing a coherent explanation of the effects of given independent variables[55].

Therefore, this study independently explained the mechanisms by which each pathway acted individually, analyzed the differences in their effect values through the parallel mediation model, and furthermore analyzed the unified coherent effects of the mediating variables through the chain mediation model. The present study adopted these two mediation models to deeply explore the path relationships among professional identity, academic self-efficacy, and learning engagement.

Research methodology

Participants

This study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Jimei University(No.12/20240416). Informed consent was obtained from all participants involved in this study. Convenience sampling method was used to select undergraduate students in several universities (Jimei University, Jilin Agricultural University, Wuxi Taihu University, Chengde Medical University, Fujian Medical University, Fuzhou University of International Studies and Trade and so on) in China to conduct the questionnaire survey. The number of questionnaires issued was 4300. After screening invalid samples (reverse

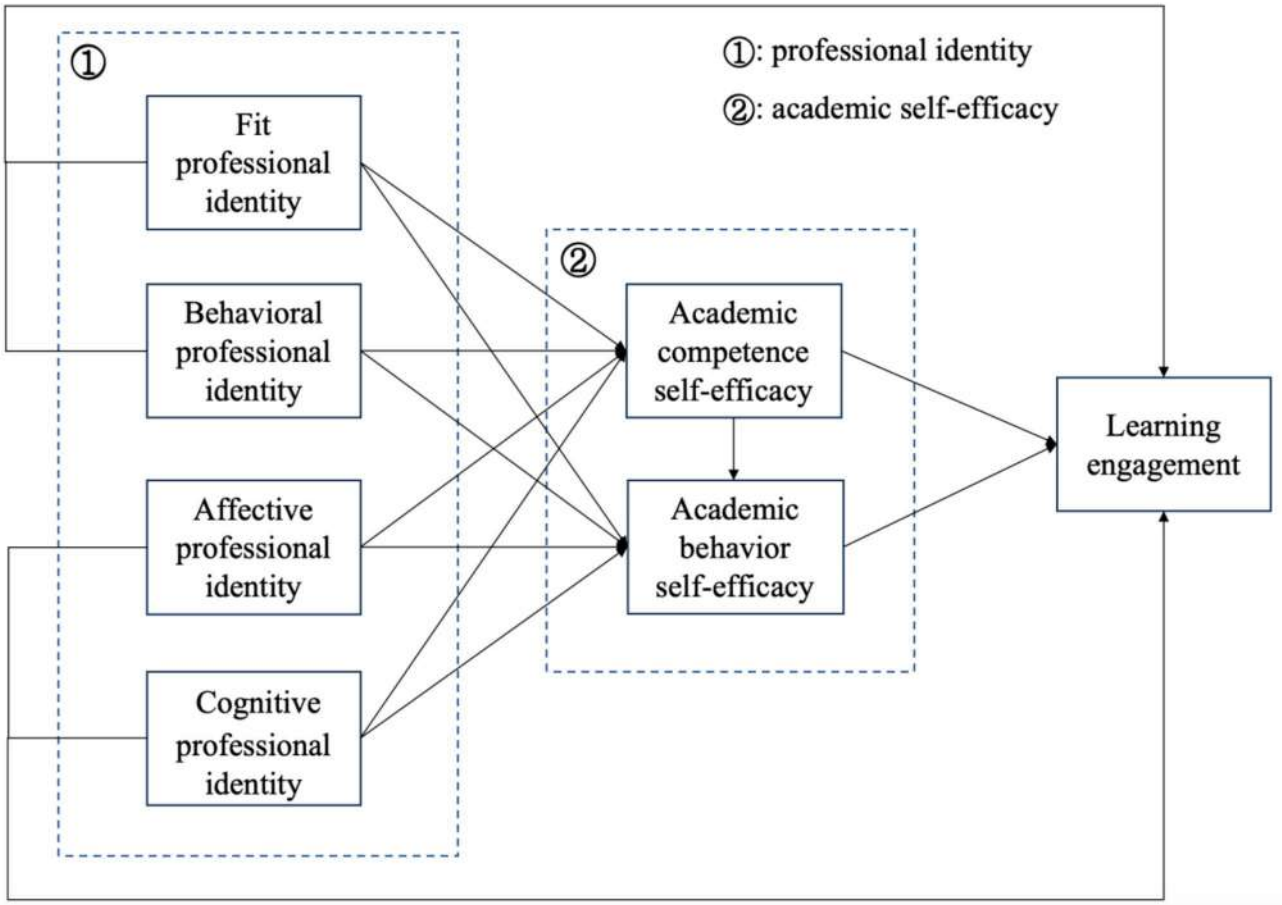

Fig. 1. Theoretical conceptual model.

questions, trap questions), 4125 valid samples were obtained, and the response rate was about 95.9%. All the participants came from four-year universities students who obtained a bachelor's degree after meeting the requirements. Higher vocational college and junior college students were excluded from participation. The age of the participants ranged from 17 to 26 years old (M = 19.734 years old, SD = 2.693), and the distribution of the samples was shown in Table 1. The raw data supporting the conclusions of this article will be available from Chunmei Chen (chunmei88@jmu.edu.cn) on reasonable requests.

Instruments

The three sub-questionnaires used in our study are all compiled by domestic scholars according to the characteristics of Chinese university students, and have good reliability and validity respectively. Moreover, in this study, these three questionnaire dimensions also had good reliability and validity regarding KMO value and Cronbach's α coefficient, which were suitable for use in this research.

The university students' professional identity questionnaire

The University Students' Professional Identity Questionnaire in this study was developed by Qin in 2009[26]. The questionnaire consists of 23 questions and is scored on a 5-point scale. The questionnaire consists of four dimensions: fit, behavioral, affective and cognitive. Fit items such as "I have good professional thinking"; behavioral items such as "I actively participate in practical activities related to my major"; affectivel items such as "I am willing to engage in work related to my major"; cognitive items such as "I understand the employment situation of my major. I am aware of the employment situation of my major", etc. The questionnaire has no reverse scoring questions. The higher the individual's score on a dimension (dimension mean), the stronger the individual's professional identity on that dimension, and conversely, the weaker the individual's professional identity on that dimension. In the total scale measure, the higher the total scale score (total mean score), the stronger the overall professional identity of the individual. The Cronbach's α coefficient and KMO value of this questionnaire in this study were 0.907 and 0.965 respectively.

The university students' academic Self-efficacy questionnaire

The University Students' Academic Self-efficacy Questionnaire in this study was developed by Liang in 2002[37]. The questionnaire consists of 22 questions with a 5-point scale. The questionnaire consists of two dimensions: academic competence self-efficacy and academic behavior self-efficacy. Academic competence self-efficacy has items such as "I believe I have the ability to do well in my studies"; Academic behavior self-efficacy such as "When I review for a test, I am able to review what I have learned before and after in a coherent way". The scores of all items were averaged by reversing the scores of the reverse questions, and the higher the mean value, the higher the academic self-efficacy of the individual. The Cronbach's α coefficient and KMO value of this questionnaire in this study were 0.921 and 0.951 respectively.

The university students' learning engagement questionnaire

The University Students' Learning Engagement Scale Questionnaire in this study was developed by Wang in 2014 in his PhD thesis[56]. The questionnaire consists of 22 entries on a five-point scale. Relevant items such as "I will study in advance what the teacher has taught in class"; "I actively participate in group discussions"; "Learning gives me a strong sense of satisfaction". The questionnaire has no reverse scoring questions. The ratings of all items were averaged, with higher means indicating a higher level of individual learning engagement. The Cronbach's α coefficient and KMO value of this questionnaire in this study were 0.896 and 0.963 respectively.

Statistical analyses

To achieve the study objectives, we employed a systematic analytical approach consisting of the following steps:

Name	Options	Frequency	Percentage(%)
Gender	Male	1767	42.84
	Female	2358	57.16
Grade	First grade	2247	54.47
	Second grade	943	22.86
	Third grade	561	13.60
	Fourth grade	187	4.53
	Others	187	4.53
Major	Science and Engineering	1958	47.47
	Arts	842	20.41
	Agronomy	505	12.24
	Medicine	355	8.61
	Others	465	11.27
Total		4125	100.0

Table 1. Sample distribution.

Descriptive statistics
We initially conducted descriptive statistical analyses to examine the fundamental characteristics of the dataset. This included calculating means, standard deviations, and frequency distributions for all key variables.

Common method Bias assessment
To identify and evaluate potential standard method bias, we performed Harman's single-factor test following established procedures[57]. All measurement items were entered into an exploratory factor analysis, assuming that a single factor would emerge from the unrotated factor solution if substantial standard method variance were present.

Correlational analysis
Pearson correlation coefficients were calculated to examine the bivariate relationships among the study variables. This preliminary analysis provided initial insights into the strength and direction of associations between variables.

Multicollinearity diagnostics
To ensure the robustness of our regression-based analyses, we conducted variance inflation factor (VIF) diagnostics. A threshold of VIF < 5 was used to indicate the absence of problematic multicollinearity among predictor variables.

Mediation analysis
We employed Hayes' (2017) PROCESS macro (Version 3.5)[58] to test our mediation hypotheses. Specifically, Model 4 was used to examine parallel mediation effects; Model 6 was applied to investigate serial mediation pathways. The significance of mediation effects was tested using bias-corrected percentile bootstrap methods with 5,000 resamples. A 99% confidence interval was adopted, with effects considered statistically significant when the interval did not include zero[59].

All statistical analyses were conducted using SPSS 26.0 with the PROCESS macro extension.

Results
Common method bias test
In this study, data were collected using a self-report method. While this approach is straightforward to implement, it carries the risk of introducing common method bias, which may compromise the accuracy of the study's findings. To evaluate the extent of such bias, the Harman single-factor test was employed. This method assesses the presence of common method bias by conducting a principal component analysis to determine whether a single factor accounts for an excessive proportion of the variance in the data. The results of the test showed that there were a total of 13 principal components with eigenvalues greater than 1, and that the first principal component explained only 34.654% of the total variation, which did not exceed the standard threshold of 40%[60]. Based on this result, it can be concluded that the data of this study were not affected by serious common methodological bias. This finding enhanced the validity and credibility of the results of the study and showed that even if the self-reporting method was used to collect the data, the accuracy and reliability of the study was still guaranteed when appropriate statistical tests were put in place.

Descriptive statistics and correlation analysis of the variables
In this study, we used Pearson's correlation analysis[61] to investigate the relationship between standard deviation, professional identity, academic self-efficacy, and learning engagement. The results (as shown in Table 2) of the study revealed that the correlation coefficient between professional identity and academic self-efficacy was 0.643, indicating a significant moderate-strength positive correlation between the two ($p < 0.01$). This finding implied that students' identification with their major may be related to their academic self-efficacy. Further, the correlation coefficient between professional identification and learning engagement was 0.759, indicating a strong positive relationship ($p < 0.01$). This implied that there is a positive relationship between students' identification with their major and their learning engagement. Finally, the correlation coefficient between academic self-efficacy and learning engagement was 0.761, which also showed a strong positive correlation ($p < 0.01$). This result suggested that the stronger a student's academic self-efficacy, the deeper his/her learning engagement is likely to be. This finding was consistent with the existing literature on the positive correlation between academic self-efficacy and learning engagement.

Further, the relationship between the sub-dimensions of professional identity (fit, behavioral, affective, and cognitive) and the sub-dimensions of academic self-efficacy (academic behavioral efficacy, and academic competence self-efficacy) was analyzed (as shown in Table 3). The results showed that there were generally significant positive correlations between these variables, all of which reached statistical significance ($p < 0.01$).

	Mean	Standard deviation	Professional identity	Academic self-efficacy	Learning engagement
Professional identity	3.745	0.693	1		
Academic self-efficacy	3.496	0.562	0.643**	1	
Learning engagement	3.728	0.669	0.759**	0.761**	1

Table 2. Descriptive statistics and correlation matrix for each variable. Note: ** $p < 0.01$

	Mean	Standard deviation	Fit	Behavioral	Affective	Cognitive	Academic behavior self-efficacy	Academic competence self-efficacy	Learning engagement
Fit	3.593	0.833	1						
Behavioral	3.784	0.756	0.790**	1					
Affective	3.733	0.816	0.743**	0.761**	1				
Cognitive	3.842	0.707	0.580**	0.658**	0.672**	1			
Academic behavior self-efficacy	3.383	0.472	0.526**	0.589**	0.477**	0.471**	1		
Academic competence self-efficacy	3.609	0.720	0.620**	0.609**	0.518**	0.496**	0.768**	1	
Learning engagement	3.728	0.669	0.688**	0.753**	0.645**	0.617**	0.697**	0.731**	1

Table 3. Correlations between sub-dimensions. Note: ** $p < 0.01$

Among the sub-dimensions of professional identity, the correlation coefficients of behavioral with the other three dimensions (fit, affective, and cognitive) exceeded 0.7, showing a strong correlation. Similarly, among the sub-dimensions of academic self-efficacy, the correlation coefficient between academic behavior self-efficacy and academic competence self-efficacy was 0.768, which also indicated a strong positive correlation between them. In addition, the correlation between these sub-dimensions and learning engagement was also of interest. Learning engagement had the highest correlation coefficient with behavioral (0.753), followed by fit (0.688), suggesting that learning engagement was more strongly associated with these dimensions. Precisely, the behavioral dimension reflected students' actual actions and efforts in learning, which was highly consistent with the direct manifestation of learning engagement. In contrast, the adaptive dimension reflected students' ability to adapt and adjust to the learning environment, which was also closely related to learning engagement. In addition, the strong correlations between learning engagement and academic behavior self-efficacy (0.697) and academic competence self-efficacy (0.731) further indicated that academic self-efficacy played an important role in promoting students' learning engagement.

The relationship between professional identity and learning engagement: a parallel mediation model

After conducting the initial analyses of this study, we found a significant correlation between the variables examined, which triggered the attention of this study to the issue of potential covariance. In order to ensure the accuracy and reliability of further effect tests, the predictor variables were standardized in this study prior to the formal test, and the data set was also diagnosed for covariance. The results of the covariance diagnostics indicated that the Variance Inflation Factor (VIF) values for all the predictor variables ranged from 2.056 to 3.742, which were significantly below the thresholds 5 that is commonly used to indicate serious covariance problems. This indicated that there were no serious covariance problems in the data-set used in the present study, ensuring that the data were suitable for further mediation effect tests[62].

Next, this study utilized the Process plug-in developed by Hayes to assess the path of impact of professional identification on learning engagement and the parallel mediating effects of academic competence self-efficacy and academic behavior self-efficacy in this process. This process used a bootstrap method (sample size of 5000) to determine 95% confidence intervals (CI), aiming to accurately assess the statistical significance of the mediating effect. Through the developed chain mediation model, we provided insights into how the sense of academic competence self-efficacy and the sense of academic behavior self-efficacy mediate the relationship between professional identity and learning engagement. The results of the model were presented in detail in Table 4.

Analysis of regression model coefficients

Four multiple regression linear models, corresponding to Models 1 through Models 4, were demonstrated in Table 4.

1) Model 1: i.e., the effect of the four sub-dimensions of professional identity on learning engagement. Except for affective professional identity, the other three sub-dimensions of professional identity showed a significant positive influence relationship on learning engagement, with the highest influence coefficient of behavioral professional identity *($B = 0.395, p < 0.001$)*, and the lowest influence coefficient of fit professional identity *($B = 0.174, p < 0.001$)*, and the hypotheses H1, H1a, H1b, and H1d were all Validated;
2) Model 2: i.e., the effect of the four sub-dimensions of professional identity on academic behavior self-efficacy. A similar pattern to that of Model 1 was presented, except for affective professional identity, the remaining three sub-dimensions of professional identity also showed a significant positive influence relationship on the academic behavior self-efficacy, and with the highest level of influence being behavioral professional identity ($B = 0.253, p < 0.001$), and the lowest level of influence being fit professional identity ($B = 0.087, p < 0.001$);
3) Model 3: i.e., the effect of the four sub-dimensions of professional identity on academic competence self-efficacy. All four sub-dimensions of professional identity showed a significant relationship of influence on the academic behavior self-efficacy, with affective professional identity showing a significant negative relationship *($B = -0.047, p < 0.001$)*, and the highest and lowest coefficients of the other three positive relationships being fit professional identity *($B = 0.317, p < 0.001$)* and cognitive professional identity respectively *($B = 0.148, p < 0.001$);*

	Model 1:Learning engagement					Model 2:Academic behavior self-efficacy					Model 3:Academic competence self-efficacy					Model 4:Learning engagement				
	B	**Standard error**	**t**	***p***	**β**	**B**	**Standard error**	**t**	***p***	**β**	**B**	**Standard error**	**t**	***p***	**β**	**B**	**Standard error**	**t**	***p***	**β**
Constant	0.881**	0.038	23.165	0.000	-	1.836**	0.034	53.685	0.000	-	1.124**	0.049	22.739	0.000	-	0.092*	0.043	2.137	0.033	-
Fit	**0.168****	0.014	12.363	0.000	0.210	0.087**	0.012	7.080	0.000	0.153	0.317**	0.018	17.904	0.000	0.367	0.066**	0.012	5.448	0.000	0.082
Behavioral	0.395**	0.016	24.618	0.000	0.446	0.253**	0.014	17.556	0.000	0.406	0.252**	0.021	12.056	0.000	0.264	0.262**	0.014	18.409	0.000	0.297
Affective	0.022	0.014	1.546	0.122	0.026	−0.024	0.013	−1.914	0.056	−0.041	−0.047**	0.018	−2.607	0.009	−0.053	0.040**	0.012	3.335	0.001	0.049
Cognitive	0.174**	0.013	13.304	0.000	0.184	0.095**	0.012	8.090	0.000	0.142	0.148**	0.017	8.748	0.000	0.146	0.111**	0.011	9.789	0.000	0.117
Academic behavior efficacy																0.279**	0.019	14.620	0.000	0.197
Academic competence self-efficacy																0.246**	0.013	18.623	0.000	0.265
R^2	0.611					0.367					**0.433**					0.714				
Adjustment R^2	0.610					0.366					0.432					0.714				
F value	F(4,4120) = 1615.242,*p* = 0.000					**F(4,4120) = 596.910,p = 0.000**					**F(4,4120) = 785.328,p = 0.000**					F(6,4118) = 1715.469,*p* = 0.000				
Note: *$p < 0.05$**$p < 0.01$																				

Table 4. Parallel mediation model: regression coefficients for each variable.

	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6	Path 7	Path 8
Mediated effect percentage	14.374%	46.300%	17.899%	15.657%	0%	29.140%	15.263%	21.021%

Table 5. Mediated effect percentage. Calculation of mediated effect percentage: a * b / c

Item	c Total effect	a	b	a*b Mediating effect value	a*b (Boot SE)	a*b (z value)	a*b *p* value)	a*b (95%BootCI)	c'Direct effect	Conclusion of the test
Path1:fit = > academic behavior self-efficacy = > learning engagement	**0.168****	0.087**	**0.279****	**0.024**	0.005	4.530	0.000	0.022 ~ 0.045	0.066**	**partially mediated**
Path2:fit = > academic competence self-efficacy = > learning engagement	0.168**	0.317**	0.246**	0.078	0.010	7.931	0.000	0.077 ~ 0.122	0.066**	partially mediated
Path3:behavioral = > academic behavior self-efficacy = > learning engagement	0.395**	0.253**	0.279**	0.071	0.008	8.763	0.000	0.064 ~ 0.099	0.262**	partially mediated
Path4:behavioral = > academic competence self-efficacy = > learning engagement	0.395**	0.252**	0.246**	0.062	0.008	7.875	0.000	0.057~0.0880.088	0.262**	partially mediated
Path5:affective = > academic behavior self-efficacy = > learning engagement	0.022	−0.024	0.279**	−0.007	0.004	−1.532	0.125	−0.017 ~ 0.003	0.040**	mediating effect was not significant
Path6:affective = > academic competence self-efficacy = > learning engagement	0.022	−0.047**	0.246**	−0.012	0.006	−1.941	0.052	−0.027~−0.002	0.040**	masking effect
Path7:cognitive = > academic behavior self-efficacy = > learning engagement	0.174**	0.095**	0.279**	0.026	0.004	6.267	0.000	0.018 ~ 0.037	0.111**	partially mediated
Path8:cognitive = > academic competence self-efficacy = > learning engagement	0.174**	0.148**	0.246**	0.036	0.006	6.257	0.000	0.025 ~ 0.050	0.111**	partially mediated

Table 6. Summary of inter-mediation test results. Note: ** $p < 0.01$ Bootstrap type: Percentile bootstrap method

4) Model 4: i.e., the effects of the four sub-dimensions of professional identity and the two sub-dimensions of academic self-efficacy on learning engagement. With the addition of academic behavior self-efficacy and academic competence self-efficacy, fit professional identity, behavior identity, and cognitive professional identity still showed a significant positive influence relationship, but the effect values were all reduced. Whereas, unlike in Model 1, affective professional identity showed a positive significance *(B = 0.040,p < 0.001)*. The difference between the results of Model 4 and Model 1 predicted the existence of possible mediating effects that affected the path coefficients between the independent and dependent variables.

Analysis of mediating effects

Further, we conducted bootstrap analysis of mediating effects and impact coefficients to determine whether there were significant mediating effects in each path. As shown in Tables 5 and 6, Path 5: affective = > academic behavior self-efficacy = > learning engagement showed a non-significant mediating effect. And Path 6: affective = > academic competence self-efficacy = > learning engagement showed a masking effect (i.e., the direct effect positively predicted learning engagement, but negatively reduced the total effect through the mediating effect). Except for Path 5 and Path 6, the remaining six mediating paths showed significant partial mediation effects, and the direct, indirect, and total effects were all significant positive influence relationships. Among them, path 2 had the highest mediating effect as a proportion of the total effect, at 46.3%. The highest total effect was in the influence path of behavioral-learning engagement *(B = 0.395,p < 0.001)* and the lowest total effect was in the influence path of affective-learning engagement *(B = 0.022,p > 0.01)*. In Table 5, except for the non-significant path 5: affective = > academic behavior self-efficacy = > learning engagement, the highest percentage of mediating effect was in path 2:

fit = > academic behavior self-efficacy = > learning engagement, and the lowest percentage of mediating effect was in path 1: fit = > academic competence self-efficacy = > learning engagement. At this point, hypotheses H2, H2a, and H2b were all validated.

The relationship between professional identity and learning engagement: a chain mediation model

Based on the parallel mediation in Sect. 3.3, we further investigated the relationship between the two mediating variables. Using Plug-in 6 in Process, we conducted chained mediated effects analysis through four multiple regression linear models, with the independent variables being the four sub-dimensions of professional identity, the mediator variables being academic competence self-efficacy and academic behavior self-efficacy, and the dependent variable being learning engagement. The results were shown in Table 7. Since Models 1, 2, and 4 were all the same as in Table 4, only Model 2 added academic competence self-efficacy as a dependent variable, so only Model 2 was shown in the table below.

From Table 7, we could see that there was a significant positive relationship between academic competence self-efficacy and academic behavior self-efficacy *(B = 0.435,p < 0.001)*, revealing a possible chain mediation effect. Further, we performed bootstrap analysis on the 4 chained mediated effects and the results were shown

	Model 2: academic behavior self-efficacy				
	B	Standard error	t	*p*	β
Constant	1.347**	0.028	47.739	0.000	-
Fit	−0.051**	0.010	−5.173	0.000	−0.090
Behavioral	0.144**	0.011	12.607	0.000	0.231
Affective	−0.003	0.010	−0.353	0.724	−0.006
Cognitive	0.030**	0.009	3.300	0.001	0.046
Academic competence self-efficacy	0.435**	0.008	51.892	0.000	0.664
Academic behavior self-efficacy					
R^2	0.617				
Adjustment R^2	0.617				
F value	$F(5,4119) = 1328.072, p = 0.000$				

Table 7. Chained mediation model: partial regression coefficients. Note: ** $p < 0.01$.

Item	Effect	Boot SE	BootLLCI	BootULCI	z	*p*
Chained path1	0.039	0.005	0.040	0.058	8.044	0.000
Chained path2	0.031	0.004	0.026	0.043	7.433	0.000
Chained path3	−0.006	0.003	−0.014	−0.001	−1.828	0.067
Chained path4	0.018	0.003	0.013	0.027	5.609	0.000

Table 8. Bootstrap analysis of the mediation effect test. Note: *Chained path1: fit⇒academic competence self-efficacy⇒academic behavioral efficacy⇒learning engagement Chained path2: behavioral⇒academic competence self-efficacy⇒academic behavioral efficacy⇒learning engagement Chained path3: affective⇒academic competence self-efficacy⇒academic behavioral efficacy⇒learning engagement Chained path4: cognitive⇒academic competence self-efficacy ⇒academic behavioral efficacy⇒learning engagement*

in Table 8. Among the 4 chained mediated effects, BootLLCI and BootULCI did not include 0 between them, indicating that chained mediated effects were all present[63]. At this point, hypothesis H3 was verified.

Discussion

The influence of professional identity on learning engagement

The findings of this study revealed that, with the exception of affective identity, the remaining three sub-dimensions of professional identity exerted a significant positive influence on learning engagement. Among these, behavioral professional identity demonstrated the highest influence coefficient, while fit professional identity exhibited the lowest influence coefficient. This was overall similar to the conclusions reached by existing studies, but there were slight differences.

Firstly, many studies have confirmed that fit professional identity is positively correlated with university students' learning engagement. A study of trainee nurses at Fujian Medical University in China has found a significant positive correlation between learning engagement, resilience, and professional identity. Nurse trainees with stronger professional identities who perceive themselves to be matched to their specialty are more likely to remain in nursing jobs in their future career plans. These students exhibit a greater inherent interest in their chosen field and demonstrate an enhanced capacity to transform stress and negative experiences into opportunities for personal growth and self-improvement when faced with challenges. Consequently, they have a higher level of learning engagement to their studies[64]. Another study focusing on undergraduate students majoring in tourism at 10 large public universities in Jiangsu Province, China, further corroborated that students with a strong sense of professional identity are more inclined to perceive a positive alignment between their personal growth and their chosen field of study. This alignment fosters positive learning emotions and behaviors, ultimately enhancing their level of learning engagement[65]. These students have a stronger sense of belonging to and reliance on their majors, who are willing to work hard to complete their well-developed study plans[66]. They are more interested in the development of their personal professionalism and have a higher opinion of themselves in terms of communication. High level of professionalism makes them involuntarily value their profession[67]. It can be seen that the higher the university students' fit professional identity, the more conducive to stimulate their positive learning emotions, and thus improve their learning engagement.

Secondly, it has also been established that behavioral professional identity is positively related to students' learning engagement. Nursing students who possess a robust professional identity are better equipped to coordinate the resources and competencies of an inter-professional team to address patient needs, while engaging in active reflection on their individual roles within the team. This collaborative dynamic enables the student body to learn from one another, thereby enhancing their academic performance[68]. Similarly, normal university students with higher levels of professional identity are able to use teamwork purposefully and are more likely to pay attention to whether the internships and programs offered by their schools could actually contribute to their

professional growth and practice, as well as to reflect on their behaviors in their professional learning. This group of students is willing to invest more time and resources in finding an improvement bill for the next enhancement that promotes more effective learning[69]. Whether they are nurses or normal students, the higher their behavioral professional identity, the more inclined they are to practice and reflect in teamwork and promote deep learning.

Finally, relevant studies also have confirmed that cognitive professional identity is positively correlated with students' learning engagement. A survey on normal physical education students has figured out that strengthening and enhancing students' implicit cognition of their major is conducive to mobilizing their interest in study and work, so that they can maintain a relatively full state of knowledge reception in day-to-day professional learning and internship, and thus improving their learning engagement level[70]. Students who possess a deeper understanding of the current circumstances surrounding normal university students and the teaching profession are more inclined to dedicate time and effort to acquiring professional knowledge and honing their teaching skills[71]. These students are able to understand their own professional skills and have a more detailed plan for their future development, which promotes their enthusiasm and interest in professional knowledge learning[72]. The higher the cognitive professional identity of university students, the more inclined they are to plan and prepare for future development.

However, in our study, the effect of the affective professional identity sub-dimension of professional identity on learning engagement is not significant. This is somewhat different from the conclusions drawn from existing studies[33]. This may be related to our research participants. Many Chinese students, even if they lack familiarity with or interest in a particular major, strive to fulfill the corresponding academic requirements to achieve high grades, secure scholarships, and ensure successful graduation. Nevertheless, for the sake of university students' mental well-being, their affective professional identity during the learning process must not be overlooked.

Parallel mediating effects of academic competence self-efficacy and academic behavior self-efficacy

The results of this study indicated that, with the exception of Path 5 and Path 6, the remaining six mediating paths demonstrated a significant partial mediation effect. Furthermore, the direct, indirect, and total effects all exhibited significant positive relationships. This suggests that academic competence self-efficacy and academic behavior self-efficacy function as independent partial mediators between the three sub-dimensions of professional identity (excluding affective professional identity) and learning engagement. It was worth noting that in Path 5 and Path 6, affective professional identity, while positively and significantly influencing learning engagement through the direct effect, did not produce a positive mediated influence effect through the mediating variable (with a non-significant mediating effect in Path 5 and a negative masked mediating effect in Path 6). These findings were consistent with the basic ideas of self-concept theory and self-efficacy theory.

Firstly, the two sub-dimensions of academic self-efficacy play parallel mediating roles between fit professional identity and learning engagement. Studies have confirmed that, students with low fit professional identity are prone to indulge in a depressive state of learning. They tend to believe that all behaviors are beyond individual control and they lack concrete actions to change the status for the better, and their academic self-efficacy is reduced[73]. These students tend to believe that they are unable to perform their daily academic tasks and fulfill their required student obligations. They have a lower likelihood of completing their learning program. Their learning adaptability in various learning environments is reduced, leading to their lower level of learning engagement[74]. In addition, students with lower fit professional identity tend to believe that the effort they put into their majors is unnecessary and unworthy. They advocate negative self-regulation strategies, lack the regulatory thinking of "plan first, then act", have lower levels of action control, and have lower academic behavior self-efficacy, which in turn affects their level of learning engagement[75].

Secondly, the two sub-dimensions of academic self-efficacy play parallel mediating roles in the relationship between behavioral professional identity and learning engagement. It has been established that students with a high level of behavioral professional identity demonstrate an enhanced ability to adapt more quickly to their surrounding learning environment. These students are able to consciously take ownership of their learning and regulate their behavior to solve problems in a purposeful and strategic manner. They perceive themselves as capable and experienced in mastering the uncertainties of learning and life, and improve their academic competence self-efficacy. They spend more time on academic tasks, which makes it easier for them to achieve academic success[76]. In addition, students with a higher behavioral professional identity are willing to participate in activities held in their major and are able to look at their personal future plans with a developmental perspective. In the course of their professional studies, they tend to help themselves become more aware and clear about the resources and strengths available to them. This adaptive capacity is accompanied by enhanced academic behavior self-efficacy, characterized by greater autonomy over their professional development and an increased willingness to assume responsibility for their own learning[77]. They are able to incorporate critical thinking to refine and categorize their learning content, and actively perceive and master the management of resources or rules in their learning environments, which in turn improves their engagement in learning[78]. Conversely, students with low academic behaviors self-efficacy do not like to participate in school academic and social activities such as engaging in online discussions and asking questions to peers and teachers. They have low levels of learning engagement[79].

Finally, the two sub-dimensions of academic self-efficacy act as parallel mediators of cognitive professional identity and learning engagement. Students with a high sense of professional identity have a more comprehensive and clear understanding of the nature of their major as well as clearer goals for their future personal work plans. They tend to believe that they can accomplish challenging, difficult and complex tasks and their sense of belonging to the profession is stronger[80]. These students are more confident in accomplishing their learning tasks. They are also able to allocate their personal resources more effectively when faced with challenging learning situations, which in turn increases their level of learning engagement[81]. Although many studies have explored the mediating role of academic self-efficacy in the process of professional identity and learning engagement,

their analysis and elaboration are relatively broad. Our research presents a more detailed and comprehensive understanding of the mechanism of this impact. University workers and related personnel can better promote university students' learning engagement by improving their academic competence self-efficacy and academic behavior self-efficacy.

Chain mediation effect of academic competence self-efficacy and academic behavior self-efficacy

This study found that all four chain mediation paths showed significant mediation effects, indicating that all four sub-dimensions of professional identity influenced learning engagement through the chain mediation effects of academic competence self-efficacy and academic behavior self-efficacy (in which the chain mediation path of affective professional identity-learning engagement had a negative effect close to 0, and the rest of the sub-dimensions suggest a significant positive effect). Related studies have confirmed that academic self-efficacy plays a mediating role in the influence mechanism of professional identity and learning engagement. Students with low professional identity tend to perceive themselves as incapable of accomplishing tasks and are unable to regulate their state and have less self-control. They do not adapt well to professional learning, which in turn makes them reluctant to put in the appropriate effort[82]. When faced with academic burnout, this group is more likely to indulge in it, not believing that they can complete challenging tasks and not interested in exploring optimal learning modes. Their academic self-efficacy is reduced and they are easily disturbed by negative emotions such as anxiety and depression, which in turn affects the development and implementation of their learning decisions[83]. However, few studies have clearly divided academic self-efficacy as a mediating variable into two sub-dimensions and explored its influence mechanism on professional identity and academic engagement. This is a more comprehensive exploration done in our study, and it is also consistent with the view of existing research.

It has been confirmed that there is a correlation between the two sub-dimensions of academic self-efficacy. Students with high levels of academic self-efficacy are more likely to perceive themselves as capable of organizing and executing a range of learning behaviors necessary to achieve specific learning goals, and to be able to actively use independent learning strategies and experience gained from collaborative work to overcome academic challenges. They support their own self-confidence and autonomy by striving to implement positive beliefs about their ability to succeed in a course, from cognition to action. These qualities profoundly influence their approaches to learning, empowering them to take ownership of their learning goals and proactively pursue academic achievement[84]. This group of students believe in their ability to organize and execute the actions required by the established study plan, and show more active participation as well as a hardworking outlook. As a result, they are also able to demonstrate greater perseverance and endurance in the face of difficulties, and are not willing to give in easily to difficulties and challenges. They are able to actively use self-regulated learning strategies (including time and learning environment management), actively seek available learning and social resources, and further enhance their own sense of belief in learning and intrinsic motivation. Inadvertently, they increase the amount of time and energy they devote to learning[85]. University workers and related personnel can improve students' academic competence self-efficacy through relevant measures, help them establish self-confidence, believe that they are capable to perform learning tasks, and thereby improve their academic behavior self-efficacy. Students believe that they can adopt appropriate methods to achieve their learning goals, and then stimulate their enthusiasm and initiative in learning, thus promoting their learning engagement.

Contributions, limitations and prospects

Contributions

University students' learning engagement is still a hot topic that has attracted extensive attention from scholars in various countries. This study explored the effects of the dimensions of professional identity on university students' learning engagement and the mediating role of academic self-efficacy in this process. It was found that (1) except for affective professional identity, all the sub-dimensions of professional identity showed a significant positive influence on learning engagement; (2) all sub-dimensions of professional identity except the 2 pathways of affective professional identity had positive partial mediating effects through the sub-dimension of academic self-efficacy; and (3) the sub-dimension of academic self-efficacy acted as a chain mediator in the effects of the sub-dimensions of professional identity on learning engagement.

There are a lot of studies on university students' learning engagement, such as the discussion of factors affecting university students' learning engagement[86,87], and many of them analyze the influence mechanism of university students' learning engagement in online teaching[88–90]. In addition, many studies have discussed the influence of professional identity on academic self-efficacy[91,92]and university students' learning engagement[16,93]. However, there are fewer studies on academic self-efficacy and university students' learning engagement[94,95]. Even fewer studies have examined the relationship between the three simultaneously. In this study, we also explore the relationship between different dimensions in professional identity and different dimensions of academic self-efficacy and university students' learning engagement. Specifically, compared with previous studies, we discussed the mechanism of university students' learning engagement from different sub-dimensions of professional identity and academic self-efficacy. Therefore, this study facilitates university workers and related personnel to understand the influence mechanism of Chinese university students' learning engagement more comprehensively and deeply.

On the one hand, this study enriches the theoretical research on university students' professional identity, university students' academic self-efficacy and university students' learning engagement. On the other hand, this study can provide valuable insights for university workers and related personnel to improve learning engagement among Chinese university students, particularly when considering the unique characteristics of this student population. Over the years, China's university entrance examination has played an important role in selecting talents and has been widely concerned by the society. As China's higher education system

has transitioned into a stage of massification, coupled with the limited availability of high-quality educational resources, the competition in the university entrance examination remains intensely fierce. Consequently, despite recent advocacy for quality-oriented education, exam-centric education practices are likely to persist for an extended period. Many senior high school students dedicate immense effort to preparing for the university entrance examination, often at the expense of developing their comprehensive competencies. Due to their limited participation in extracurricular activities, they have little knowledge of themselves and the careers they want to pursue in the future. Most of these students fill in the major of the university entrance examination are suggested by their parents or others, and some choose to fill in the major with the majority with the primary goal of gaining admission to prestigious "985", "211" good university. However, they don't have a clear understanding and preparation for what major they want to learn and how to plan their university life after they go to university. Combined with the above analysis and the findings of this study, we can promote the learning engagement of Chinese college students from the following aspects.

First, to improve the professional identity of university students. Career counseling for university students should be strengthened before they fill out their volunteer forms. It has been found that candidates who fill out their volunteer positions have significantly higher levels of professional identity and academic self-efficacy than those who apply for admission or transfer under the advice of others[96]. Students are unfamiliar with and do not understand their majors and are confused about the prospects of their majors; they have a low sense of identity with their majors, which in turn affects their learning engagement. Therefore, it is particularly important for the relevant departments and parents and others to strengthen counseling for students to fill in their university volunteers in the university entrance examination.Secondly, to enhance the prestige of the profession, universities should prioritize the advancement of academic discipline construction through rigorous research and elevate the professional development of faculty members. By emphasizing scholarly research and maintaining high teaching standards, universities can bolster their academic reputation, thereby fostering students' sense of identification with their chosen fields. Lastly, it is imperative to provide comprehensive guidance for students' career planning. At the beginning of the school year, Universities can help students to have a preliminary plan for their professional studies by introducing them to the basic information of their majors, professional training programs, and the scope and direction of employment. Universities can also help students gain a comprehensive understanding of their professional studies by offering lectures and career guidance classes, so that they can have a clearer picture of their career development[71,97]. At the same time, schools should also strengthen students' career guidance. Relevant staff of universities and parents should help students to understand the employment prospects of their majors, difficulties in the employment process and employment paths, etc., so as to eliminate students' confusion about the future of their majors and thus enhance their sense of professional identity.

The second is to improve university students' academic self-efficacy. Firstly, pay attention to individual differences and provide targeted guidance. Due to different family environments, own learning experiences and mastery of learning methods, there are differences in the learning levels of different students[98]. Teachers can set different learning goals so that students at different levels can accomplish them within their abilities, thereby increasing their academic self-efficacy. Secondly, teachers, parents and other significant others should provide timely and positive feedback on students' learning as much as possible, and give students more encouragement and praise, thus to help students gain a sense of accomplishment and satisfaction in the learning process. Thirdly, Universities can reduce students' anxiety about learning by conducting psychological lectures and academic counseling, guiding them to positive psychological construction, improving their academic self-efficacy, and thus increasing their level of learning engagement.

In addition, in our study, although affective professional identity is not significantly correlated with learning engagement, stakeholders should still try to improve students' affective professional identity as much as possible through counseling, lectures, and improving the teaching level of professional teachers. Although students are able to complete their learning tasks as much as possible even if they don't like or are not interested in their majors, they are prone to negative emotions such as learning burnout, anxiety and even depression, which is not conducive to the healthy development of their body and mind in the long run.

Limitations and prospects

First, this study relied on cross-sectional data and convenience sampling methods, which may have limited the representativeness of the sample and thus the general applicability of the findings. As a result, the correlations revealed in the results may not be sufficiently reflective of what is actually happening in the wider population. In addition, the nature of cross-sectional studies limits the possibility of a deeper understanding of causality, as it captures data only at a single point in time and does not allow for tracking the dynamics between variables over time. Second, there is a risk of selection bias due to the limitations of the study design. Participants may have specific characteristics or tendencies (for example, our samples are mainly from Chinese university students), which may affect the genera ability and reliability of the findings. And this study fails to use an experimental or intervention design, which limits the exploration of possible causal and mediating effects between variables. Finally, due to time and effort constraints, whether the mechanisms influencing professional identity, academic self-efficacy, and learning engagement differed across demographic variables such as gender, grade level, and major are not explored in this study. To overcome these limitations, a longitudinal design could be considered for subsequent studies to track and analyze variable changes over time. At the same time, implementating of a randomized controlled trial will help to identify and validate the causal relationship between these variables more accurately. In addition, expanding the sample size and using randomized sampling methods will enhance the study's representativeness and external validity. Follow-up studies can also conduct differential analysis of the influence mechanism. These improvements will provide a stronger foundation for a deeper understanding and explanation of the relationships among the study variables.

Data availability

The raw data supporting the conclusions of this article will be available from Chunmei Chen (chunmei88@jmu.edu.cn) on reasonable requests.

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Author contributions

CC designed the study and wrote the manuscript. YS and CC analyzed the data. CC and YZ modified the manuscript. All authors reviewed the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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Perspective

Towards the future of education: cyber-physical learning

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Abstract
Singapore University of Technology and Design (SUTD) is embarking on an educational innovation program called SUTD campusX to support its future of education. SUTD campusX aims to innovate new educational models, technology tools, and pedagogies for a new form of learning called "Cyber-Physical Learning", where the concept is that both remote cyber students and face-to-face physical students can learn and interact effectively, seamlessly, and synchronously in the same class. SUTD campusX focuses on various streams of emerging technologies such as learning analytics, immersive technologies (e.g., AR/VR/MR, metaverse learning, gamification), telepresence robotics, and personalized learning. SUTD campusX supports and innovates the signature interdisciplinary, student-centric, and team-based problem-solving active learning model of SUTD to transform it for the cyber-physical learning environment. The various innovation streams of campusX not only generate insightful learning data to create new educational frameworks and practices but also enable a learning analytics and AI-assisted platform to deliver personalized adaptive learning. In this perspective article, we describe and reflect on the forward-looking nature of the various innovation themes and how these innovations act as the front-facing technologies to collect and generate learning insights to power an AI-driven cyber-physical learning platform to realize the future of Cyber-Physical Learning at SUTD.

Keywords Cyber-physical learning · Emerging education technologies · Future of education · Higher education · Interactive learning · STEM education · Student-centered learning

1 Introduction

According to the OECD Future of Education and Skills 2030 report, we are facing unprecedented challenges now than ever before, in social, economic, technological, and environmental aspects; and this necessitates changes to higher education [1–3]. The recent COVID pandemic is a good example. Given the Volatile, Uncertain, Complex, and Ambiguous (VUCA) global context, what does the future of education look like? [4]. Although the COVID pandemic posed several challenges, it has also presented several growth opportunities. It has pushed institutions, instructors, and learners to consider ways in which we can adopt technology for more personalized, flexible, and adaptive learning experiences that are tailored to the needs and interests of individual learners. Digital technologies such as artificial intelligence, machine learning, and augmented/virtual realities have also been leveraged to enhance learning experiences and provide new forms of engagement, interactivity, and immersive learning. Big data and learning analytics have become valuable in keeping track of learning behaviour and interactions to provide timely, prompt, and individualized feedback to students. Other trends in higher education that are gaining prominence include

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continual lifelong learning and work-based learning. An important element that has surfaced from the COVID period of education is the importance of social-emotional learning, which is the process of developing self-awareness, self-control, and interpersonal skills vital for education and life. Overall, the future of education aims to equip learners with holistic competencies (knowledge, skills, attitudes, and values) through personalized, immersive, and social learning experiences that prepare them to thrive in a rapidly changing and interconnected world, with their individual and societal well-being as one of the learning outcomes [1]. This aligns with the Singapore University of Technology and Design's (SUTD) vision of being a leading research-intensive global university focused on technology and design to educate, train and grow technically-grounded leaders and innovators who are steeped in the fundamentals of Science, Mathematics, Engineering and Technology (STEM) subjects; are creative and entrepreneurial; have broad perspectives informed by the humanities, arts and social sciences; and are engaged with the world.

In this perspective paper, we present SUTD's *Future of Education* program called SUTD campusX. SUTD campusX aims to develop new educational models, technology tools, and practices in pedagogy/andragogy for a new form of learning called "Cyber-Physical Learning" (CPL), where the key concept is that remote cyber students can learn and interact just as effectively and seamlessly as face-to-face physical students in a synchronous class. SUTD campusX aims to innovate the signature interdisciplinary, student-centric, and team-based problem-solving learning model of SUTD for the cyber-physical learning environment. It leverages emerging technologies such as immersive technology, telepresence robotics, learning analytics, and Artificial Intelligence to improve and enhance learning outcomes and student engagement.

The term "CPL" is created at SUTD and is much more than blended/hybrid learning. The uniqueness of CPL is that in-class physical students and remote cyber students learn the same materials synchronously in a seamless and integrated manner enabled by different modalities of technologies while ensuring that there is social learning connectivity between cyber students, physical students, and instructors [2] without comprising the learning outcomes and objectives. CPL also takes a holistic perspective of teaching and learning, from building the learning environment for both physical and cyber students to developing the technology tools, designing and delivering the lessons, and building a learning analytics platform, while ensuring data security and privacy to aid learning progression and provide real-time and post-lesson learning intervention and support to instructors and students.

There are several challenging aspects of implementing CPL, such as effectively engaging faculty and student users, identifying appropriate technologies, pedagogies, and andragogy, addressing data privacy, management and governance issues, and operationalizing CPL for campus-wide application. In this paper, we share SUTD's CPL approach, present the vision and philosophy of SUTD campusX, and explain how the key projects of campusX enable an adaptive and personalized future of education at SUTD.

2 Educational context

2.1 About SUTD

Singapore University of Technology and Design is a research-intensive university established in 2009 as the fourth autonomous university in Singapore. As a young university, SUTD could shape its educational approach to be innovative and future-ready from the start. SUTD offers undergraduate, postgraduate, and continuing adult learning courses/programs in architecture and engineering. SUTD's undergraduate education is characterized by (i) design thinking-based maker learning, (ii) collaborative active learning (iii) multi/interdisciplinary curricula, (iv) providing wide-ranging student experience opportunities (e.g., Capstone projects, internships, research opportunities, international exchange programs), and a (v) T-shaped education, where the first year provides the foundational Science, Technology, Engineering, Arts/Humanities and Mathematics (STEAM) education, followed by specialization in the later years [5]. SUTD encourages its faculty and instructors to evaluate and determine the appropriate pedagogy/andragogy to adopt for their classes. Instructors use a range of appropriate discipline and course-specific student-centric teaching methods (e.g., flipped learning, project-based learning, studio-based learning in tandem with teacher-centric teaching methods (e.g., lecture/demonstration.). In 2018, SUTD was recognized as the top-cited emerging engineering university globally [6].

2.2 Vision of SUTD campusX

The challenges faced by SUTD in moving to online learning are due to a significant extent of hands-on and collaborative group-based learning in our curriculum, both of which are difficult to be substituted in an online format. While our aim is not for every class or course to adopt CPL, we aim to be prepared for the future of education by developing practices and frameworks that are equally efficient and effective for completely face-to-face, online, and most importantly for CPL situations.

Existing educational technology tools have limitations in terms of supporting multi-discipline, collaborative, and hands-on problem-solving learning at SUTD. For instance, how can we get cyber-physical teams to collaborate, co-design, and build a prototype synchronously? How would instructors ensure that cyber students are participating effectively in a CPL class? How would the cyber students draw the attention of instructors and students present in the physical class? Hence, new technologies and teaching methodologies are required to be developed to meet the needs of higher-order human-centered and design-based collaborative learning. Therefore, SUTD aims to leverage the latest digital learning pedagogies and cutting-edge technology to advance itself as a future-ready university to prepare lifelong tertiary learners with its campusX initiative. SUTD campusX involves conceiving and developing the latest and best-practice pedagogies/andragogies and technologies (such as immersive extended realities, gamification, personalized learning, interactive robots, and learning analytics) to provide human- and design-centered education experiences in the form of personalized, immersive, collaborative, and socially connected learning.

The vision of campusX is to pioneer a fun, safe, and inclusive educational experience at SUTD, where lifelong tertiary learners (undergraduates, postgraduates, and adult learners) can leverage innovative cyber-physical techno-pedagogies to personalize their learning journeys and achieve optimal learning outcomes. To achieve the vision for SUTD campusX, a group of 70 teaching, research, and professional staff are currently involved in innovating and test-bedding the efficacy of new technologies and pedagogies/andragogies for CPL. From the consultations and various dialogues with students, adult learners, instructors, and the SUTD leadership team, SUTD campusX has identified three important themes focusing on user experience and learning outcomes (See Fig. 1):

- Learning Intimacy/Learning Socialisation: How can students (cyber and physical) learn better?
- "Anywhere, Anytime, Anyone" Learning: How can students have various options to learn?
- Safeguarding Governance: How can students learn in a fun, safe, and inclusive environment?

The three themes are powered by the two enablers, "Learning Science" and "Education Technology".

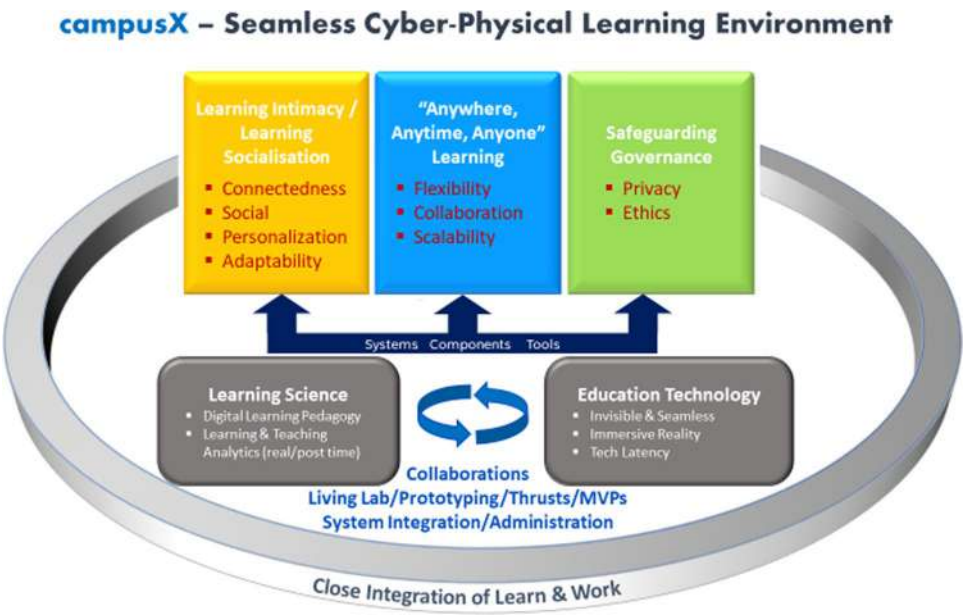

Fig. 1 SUTD campusX – Seamless Cyber-Physical Learning Environment [2]

2.3 Philosophy of SUTD campusX

SUTD campusX is powered by "Learning Science" and "Education Technology", together with the interactions between these two enablers. Learning science involves educational pedagogies, teaching and learning principles and methods, including learning analytics (both real- and post-time); while education technology involves applications, software, and hardware tools that provide seamless and immersive learning experiences (such as virtual/augmented reality, gamification, robotics, learning analytics, and artificial intelligence). The two enablers ("Learning Science" and "Education Technology") interact through various campusX programs and initiatives (e.g., partnerships, research, and innovation projects), and it is through these interactions that outputs that contribute to the development of campusX are generated. One such output is knowledge, expertise, and competency to create a campusX pedagogy/andragogy that is suited to the human- and design-centric curriculum of SUTD, termed SUTD Technology of Learning (ToL). This unique blend of SUTD Techno-Pedagogy has three important dimensions: Technology of CPL (ToCPL), Science of CPL (SCPL), and Ethics of CPL (EoCPL) (Fig. 2).

The Technology of CPL involves knowledge and competency in the various technology platforms and tools that enable CPL such as learning analytics, artificial intelligence, and robotics, while the Science of CPL involves proficiency and understanding of pedagogical and andragogical principles and techniques that support effective CPL for lifelong tertiary learners, and lastly, Ethics of CPL involves comprehension and capability to discern appropriate rules and guidelines to provide a fun, safe, and inclusive learning environment. Together all these three dimensions constitute the Technology of Learning (ToL) at SUTD campusX, which creates a unique educational experience at SUTD that centers on interdisciplinary learning and research and nurtures lifelong tertiary learners who are design-focused and human-centered.

Overall, the central thinking behind campusX is that CPL, when powered by education technology and learning science, is an intimate, interactive, and impactful learning pathway that will drive educational innovations to improve learning outcomes, grow skills and knowledge, and sustain personalized lifelong tertiary learning in a fun, safe, and inclusive way. To achieve these important outcomes, SUTD is conducting various innovation design projects, prototyping trials, and partnership activities to develop appropriate pedagogy/andragogy and technology tools that can enable SUTD to create a human- and design-centric CPL environment, i.e., SUTD campusX.

2.4 Realising CPL at SUTD

To address the 3 user themes of "Learning Intimacy/Learning Socialisation", "Anywhere, Anytime, Anyone" Learning, and "Safeguarding Governance", SUTD campusX has embarked on a set of thrusts (i.e., key projects) to develop the required human- and design-centric capabilities, pedagogical/andragogical practices, and educational tools to realise the vision

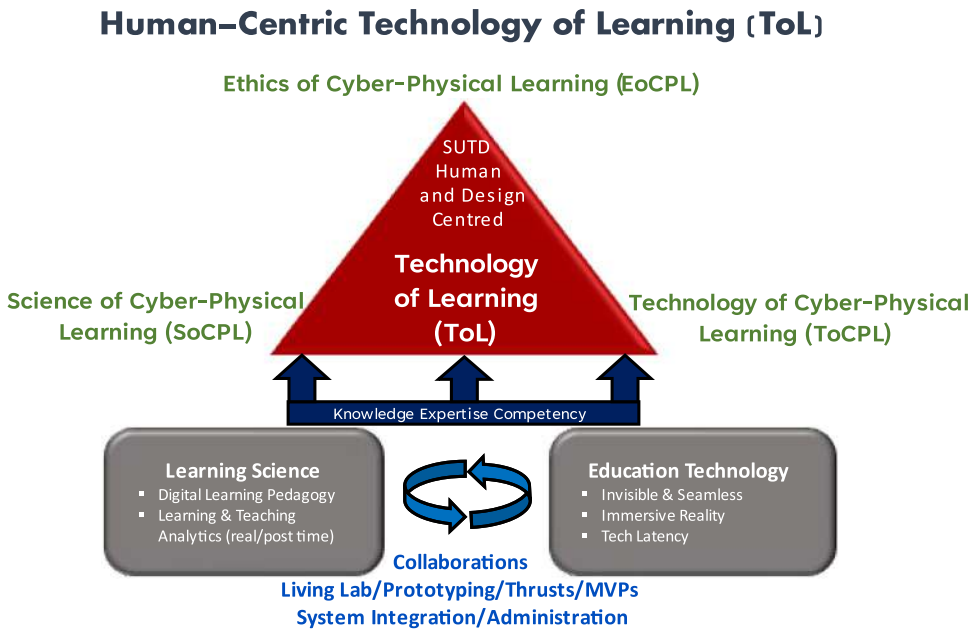

Fig. 2 SUTD campusX Human-Centric Technology of Learning [2]

of CPL at SUTD. These 6 thrusts are intended to focus not only on a strategic set of activities within themselves but also the interactions and integration across them to build a holistic and comprehensive educational system.

These six thrusts are:

1) People-centric learning and design
2) Immersive realities learning
3) Metaverse and blockchain for learning
4) Socially interactive educational robotics
5) Advanced learning analytics (including real-time analytics)
6) Enhanced learning through innovative technology

Currently, there are approximately 70 members in the SUTD campusX initiative and they work on specific projects in cross-functional teams comprising faculty members, students, administrative support staff members, and even industry partners. The following sections describe the significance and contribution of the key activities of these six thrusts, starting with the innovation learning spaces, to emerging technologies that help build the CPL environment, and finally to the underpinning learning analytics platform. Each of these projects typically involves 10—14 core team members and is led by faculty members specializing in that specific area. Projects are carried out in progressive phases, with multiple rounds of inputs and feedback from stakeholders at each stage.

3 SUTD campusX initiatives and projects

An Overview of the SUTD campusX initiative and projects are shown in Fig. 3 below.

3.1 Living labs

The learning space is an important component and contributor to learning. Living Labs are defined as "physical regions or virtual realities in which stakeholders form public–private-people partnerships (of firms, public agencies, universities, institutes, and users) for collaborating, creating, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts [7]." The European Network of Living Labs (ENoLL), an umbrella organization for living labs around the world, defines them as "open innovation ecosystems in real-life environments using iterative feedback processes throughout a lifecycle approach of innovation to create sustainable impact. They focus on co-creation, rapid prototyping, testing, scaling-up innovations & businesses, and providing (different types of) joint-value to the involved stakeholders" [8]. Similarly, the SUTD campusX Living Labs are innovative learning spaces for novel pedagogical/andragogical tools and systems that allow educators and students (both physical and cyber) to teach, communicate, and learn in a conducive cyber-physical environment. The Living Labs allow SUTD campusX teams to ideate and design solutions and prototype systems and products to resolve and address the barriers of teaching and learning in a cyber-physical setting.

Some features available in the Living Labs include:

- Telepresence learning systems for cyber and physical students to participate actively in team-based learning.
- Sensors and camera systems to support real-time data collection for learning analytics.
- Immersive Augmented Realities/Virtual Realities and Mixed Realities (AR/VR/MR) systems.
- Audio visual systems to facilitate teaching and learning in a cyber-physical environment.
- High speed and large bandwidth network for live streaming.

There are 3 SUTD campusX Learning Labs and each lab serves a different purpose and target audience. The first Living Lab is used for piloting campusX products and systems meant for undergraduate (UG) programs, as it offers a similar learning environment as the existing classrooms of UG students. For example, the lab was used to test bed a campusX gamified telepresence robot platform to help UG students and instructors learn and interact better in CPL. In this project, 360-degree camera, sensors, and real-time video analytics were used to measure both cyber and physical student engagement. This Living Lab will also be used to design and test solutions for an SUTD campusX future classroom to provide an immersive and integrative CPL environment.

Fig. 3 Overview of SUTD campusX Initiatives and Projects

The second Living Lab is being set up in collaboration with a government agency 'Skills Future Singapore (SSG)' and an adult learning research institution 'Institute for Adult Learning (IAL)'. The collaboration hopes to pioneer and advance CPL for lifelong adult learners, with the purpose of exploring new digital adult learning frameworks, andragogies, practices, and educational technologies for future Continuing Education and Training (CET) learning. Living Lab 2 will be used to develop and pilot CET training modules or courses using CPL platform as well as carry out innovation research in CPL for adult learners.

SUTD's third Living Lab is an Immersive Realities Lab to experiment with new AR/VR/MR technologies and associated pedagogy/andragogy for these immersive technologies. It will be a consolidated immersive hub at SUTD, with a highly configurable "play-and-plug" space to allow for a variety of experimental and modular immersive setups, such as real-time, multi-user simulation studios and visualization projects. Together the three Living Labs provide an innovative learning environment for the experimentation, analysis, and evaluation of emerging CPL educational models and technologies for both Pre-Employment Training (PET) and Continuing Education and Training (CET) educators and learners. 5G network is being explored to better network all the Living Labs and labs with collaborators. The next section illustrates the key projects that SUTD is undertaking to advance and realize the CPL vision of SUTD campusX, in areas such as telepresence robots, extended realities learning, gamification, metaverse, personalized learning, and learning analytics.

3.2 Telepresence learning system (telepresence robots for socially interactive learning)

One of the key goals of SUTD campusX is to bring the physical, hands-on, and immersive learning experience to remote students, as if they are physically present in the classroom and learning together with their fellow teammates. This kind of CPL could foster both remote and physically present students' engagement, social presence, increase their feeling of

belonging, build trust, and augment their ability to contribute ideas in an authentic way [9]. To achieve this vision, we decided to develop and make a telepresence learning robot system (Fig. 4) by ourselves for remote students who want to experience group-based, collaborative learning at SUTD, where each team consists of 5 to 6 students working on a common project in a physical classroom among other 7–8 teams.

The key features of SUTD's Telepresence Learning System include:

LED signalling and rotating lights that inform the instructor of remote students' learning status. Through our preliminary user studies, we identified that remote students' learning status was easily ignored by the instructor in the physical classroom simply because it was hard for the instructor to look at the computer screen (e.g., the "Zoom" interface) all the time in a hybrid teaching mode. Thus, LED lights that are easily visible to instructors all the time can catch instructors' attention more effectively.

A 360-degree camera coupled with VR headsets for remote learners. To enhance remote students' sense of social presence as much as possible, remote students wearing the VR headset could see the physical classroom through the 360-degree camera on the robot. Through our preliminary user study, remote students enjoy the freedom of seeing 360-degree views of the physical classroom in the VR headset.

A laser pointer controlled by remote learners to better engage in physical learning activities. In group learning activities, students constantly need to interact with physical items or tools for more effective learning. For instance, students may need to point at notes on a whiteboard, parts of a physical prototype, or places on a projection screen for in-class discussions. These "pointing" scenarios are very commonly seen in a physical classroom. Thus, with a controllable laser pointer, we hope remote students can also enjoy the "pointing" freedom that used to be a privilege for physically present students only.

The current telepresence learning system is a prototype serving as the starting point of human-centered design, engineering, and evaluation. Our team conducted two focus-group sessions with 9 undergraduates and 3 faculty members at SUTD to identify the pros and cons of this system to identify potential new features for the next version. A key finding was that they see the advantages of CPL in specific circumstances, such as when a student is not able to attend a class due to illness, students have an overseas exchange program, or when participants learning from distance such as their workspace etc. Interestingly, students found the 360-camera to be useful in making them feel connected to the class. Teachers also found the LED signalling and rotating light to be useful in being informed of the online students' questions. Students and teachers indicated that more refinement was needed in terms of laser pointer usage in a virtual environment. Currently, we are exploring how to enhance the virtual online learning experience and introduce more social features in terms of its appearance and interactions [10–12] in the next version, so that our telepresence design is more appealing to students and can reflect the learning status and emotional states of remote students in a more natural and effective way. Our aim is to keep refining and enhancing the User Interface (UI)/User Experience (UX) by addressing all

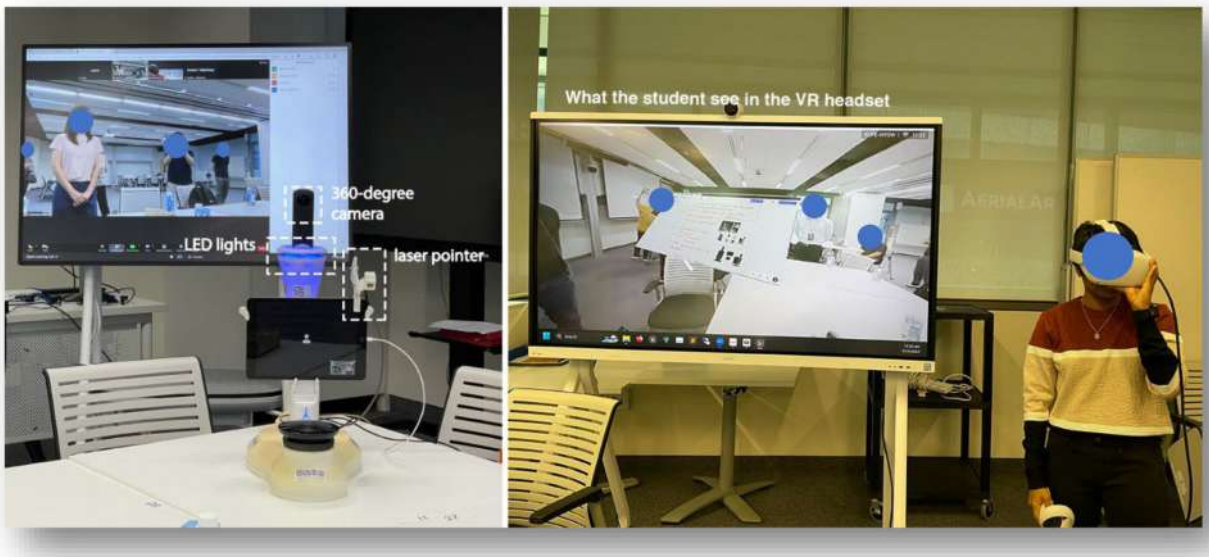

Fig. 4 Telepresence Learning System (Left); Integrated with Virtual Reality Affordance (Right)

the pain points of users in CPL. A socially interactive telepresence learning system has the potential to greatly increase remote learners' social presence, motivation, and engagement and will bring exciting opportunities for the future of cyber-physical teaching and learning. The telepresence learning system, with its visual and audio features, also serves as a front-facing sensor to collect data for learning analytics.

3.3 Project athena—a gamified metaverse for learning

Gamification and metaverse are useful innovative tools to increase university students' motivation [13] with a positive effect on learning outcomes [14]. As part of the campusX initiative, SUTD set out to develop Project Athena, a gamified metaverse application that aims to enhance the traditional learning experience by providing a gamified virtual campus to accompany the students on their learning journey. Project Athena creates a socio-spatial virtual campus that connects students and educators, providing a platform for learners to develop real-world life skills in a gamified environment. The app is specifically designed to encourage the development of positive learning behaviours, stimulate learning, and peer-connections to guide students through a learning path, and foster a better learning experience. Project Athena is a key component of SUTD's campusX project for CPL, and it integrates different backend systems in its gamified front end. Project Athena has several gamification strategies and features to enhance student engagement and promote positive learning outcomes, and these are described below.

Space features in the app such as the Campus Hub, Classroom, and Private space simulate the real SUTD campus. The app provides virtual spaces for connection, resources, and collaboration. In particular, the Classroom feature helps in classroom management and keeps students and instructors informed with a myriad of data at the right moment, such as course schedules. Through a unique check-in system, teachers are relieved from tedious activities such as attendance taking, and students can get feedback on their time-management skills.

Persona feature allows for personalization through avatar design. Just like in many entertainment-oriented games, as well as on social media, each student can choose their profile or avatar. This feature enables students to build portfolios showcasing their academic achievements, which they can customize with assets awarded from completing activities such as Quest, Classroom, and Skill Tree. In addition to being able to host their virtual space, students can invite visitors who can navigate the space using avatars and interact with both the host and objects in the room. To safeguard the integrity of the profile space, the metadata is stored in a blockchain token [15].

Skill Tree feature is a key component of the Project Athena metaverse, providing students with a clear and comprehensive view of their learning plan and the competencies required to achieve their goals. By tracking progress and recommending gamified activities to motivate and re-engage students, the skill tree offers a valuable tool for learners. In addition, the skill tree tracks students' acquisition of real-world life skills through the courses taken and unlocks challenges that reward them with exclusive content, badges in the form of non-fungible tokens (NFTs), and in-game points that they can use to win real-life competitions.

Quest feature (Fig. 5) is another important tool within Project Athena's gamified metaverse. Quests offer a way for students to retain knowledge and build their confidence through innovative gameplay. By participating in subject-specific challenges related to the material covered in class, students can assess their competency and receive rewards such as achievement badges and tokens that unlock exclusive content. The quest feature is highly flexible and can integrate with a variety of gameplay types to provide a fun and exciting learning experience.

Rewards feature motivates the students through exclusive badges and tokens when they complete the challenges. This is also a form of feedback to students. In addition, Project Athena is working in collaboration with a campusX eye tracking project to provide feedback on students' collaboration during class, which will allow for extra in-game points and rewards.

Blockchain token feature is an integral component that validates student achievements from the quest, classroom, and skill tree features. Non-Fungible Tokens (NFTs) are awarded to students who attain outstanding academic achievements and complete milestones in the skill tree. These NFTs are securely stored on the blockchain and can be used by prospective employers to evaluate a student's competencies and job suitability. The use of NFTs for academic achievements is gaining traction, with some studies showing that they can enhance student motivation and provide a secure and verifiable way to record and showcase academic achievements. Additionally, blockchain technology has been explored as a tool to verify educational credentials, thereby increasing their credibility, and reducing fraud. The incorporation of blockchain and NFTs in Project Athena aligns with the ongoing efforts to explore the potential benefits of blockchain technology in education.

Backend analytics feature integrates gamification feature with real-life classroom activities to encourage the students to adopt positive behaviour such as punctuality, engagement, and knowledge retention. For instance, students'

Fig. 5 (Left) Quest Path. (right) Example of Quest Gameplay

attendance, engagement, and performance can be mapped through the centralized data warehouse as students check in and go through the learning activities. The profile feature not only serves as a visual representation of the student's accomplishments but also provides a means for students to interact and engage with their peers and educators in a more immersive and dynamic way. By leveraging data analytics from the central warehouse, we can also visualize academic performance holistically using the profile. By incorporating this feature, Project Athena aims to provide students with a more engaging and interactive learning experience and thereby generate positive effects on their academic performance and outcomes.

One of our main design considerations has been digital equity [16], i.e., we want to ensure that all students are able to access this metaverse regardless of their financial status/which devices they own. Hence, while many envision a realistic perfectly replicated 3D twin metaverse [17], we deliberately opted to use optimized, low-polygon digital assets that require fewer hardware resources to render. In addition, we confine augmented reality experiences to external hardware and use graphic shaders to produce a high-quality product. This allows for a visually appealing metaverse while accommodating different devices'computational limitations. Students with low-end mobile phones should thus still be able to access Project Athena. Additionally, in cases where a student needs to host a multiplayer experience for a larger audience, the application can be run on a computer, it is not limited to mobile platforms.

Overall, Project Athena represents an exciting innovation in the field of education, and we look forward to further developing and fine-tuning the features of this app for next-generation learning, including NFT-based reward strategies for skill development. We are currently conducting user studies of the various features of Project Athena. We are now planning the first live tests and user studies at SUTD to quantify the effectiveness of the elements in Project Athena in improving learning outcomes. We will also integrate this project with other campusX projects.

3.4 Immersive learning

CPL aims to integrate digital and physical worlds to liberate learning and teaching from physical constraints to enhance the learning experiences, allowing wider collaborative efforts in many forms among stakeholders in teaching and learning. Immersive learning with Augmented Realities/Virtual Realities and Mixed Realities (AR/VR/MR) technologies is one of the most effective tools that deliver such objectives [18]. AR/VR/MR could provide students and teachers with engaging virtual and augmented reality tools and environments that simulate real-life situations, allowing participants to experiment and explore freely in more engaging ways, yet in a safe and controlled manner. The tools also open new ways for students to learn concepts especially ideas that are more abstract and challenging to comprehend, as AR/VR/MR could easily be used to visualize the concepts in ways that were not possible before with traditional teaching methods. With AR and VR, educators can create an interactive experience by overlaying digital information on real or virtual world objects, providing students with a more in-depth appreciation, and understanding of the subject matter. Immersive learning with AR and VR technologies can also help to develop teamwork and collaboration skills. Students can work together in a virtual environment, collaborating on projects and solving problems together. This can help to develop communication and leadership skills, which are essential for success in the workplace [19–21].

Our project focuses on working with instructors from many different courses to create engaging AR/VR/MR contents to address pain points in the courses especially those that involve visualization of difficult and abstract concepts, by allowing students to interact with virtual objects or in virtual environment engagingly, such as engineering students learning projectile motions in physics through simulations and visualizations using augmented reality [22]. Students could freely engage the virtual objects or virtual representation of the concepts, and explore them from different perspectives, with more information overlayed conveniently to emphasize the ideas. However, it is also important to recognize that the effectiveness of the tools is highly dependent on the ways they are being used, and not all subject matters may be suitable for AR/VR/MR platforms. Therefore, through these collaborative efforts, we aim to study the most effective pedagogy for teaching with AR/VR/MR content, to gain insights into the best way to design such content, and the optimum way to engage students that enhances the learning objectives. Additionally, we target to develop content creation tools that are user-friendly for instructors to create AR/VR/MR content intuitively so that it is convenient for instructors to transform concepts into virtual reality and explore ways of teaching more creatively. This would help to address the challenges and long cycle time normally required to generate the content and allow wider adoption of the AR/VR/MR technologies as an effective teaching tool that makes learning more engaging and more effective.

One of the efforts undertaken is the development of AR projectile cannon for the course "Physical World" (first-year introductory physics course on classical mechanics and thermodynamics) as an individual/team base learning platform for concepts involving projectile motion. Students often find it challenging to integrate information about the position, velocity, and acceleration of the projectile over the trajectory in the air. By creating a virtual projectile superimposed onto the real environment with AR technology, students could work individually or collaboratively to understand the kinetics and dynamics of the projectile motion, with measurements overlaying the trajectory of the virtual projectile. Students can visualize the motion in detail and conveniently from different angles that would not have been possible. The AR platform is also infused with gamification elements so that students could compete in a battlefield setting, shooting projectiles in the most effective and efficient ways by applying the physics learned. Once the development is completed, it will go through several rounds of optimizations and study of the most effective pedagogy before implementation in the course as part of the learning curriculum. A plethora of usage data such as the time of interaction and movement of the devices can be collected for detailed analysis to understand how students engage the AR content and correlate to the learning outcomes. This will be used to inform how the AR platform can be further optimized before implementation in all the classes as part of standard curriculum. Learning and usage data on student engagement and achievements would be integrated into learning analytics to further enhance learning.

3.5 Personalized learning

Personalization of learning is providing targeted and tailor-made teaching for individual learners, so that we help them achieve their potential. This is one of the intended outcomes of CPL [23, 24]. Personalized learning can be

delivered in many ways using emerging technologies. One simple way is to allow learners to choose their own learning paths, to learn at their own pace, according to their prior knowledge and readiness. Many learning environments in schools assume that students have the same prior knowledge and skills needed for specific learning activities. Typically, learning activities are designed assuming that everyone has the same skills and can follow the activities at the same pace. However, students come with varied prior knowledge. Personalization can be done by allowing students to go through different paths and taking learning content and activities that are different depending on their starting state. Learners' prior knowledge can be assessed through simple quizzes and self-perception questionnaires. Through these assessments, an adaptive learning system can determine whether the learners have the necessary prior knowledge. If not, the system can identify the gaps that the students need to address. The system can then deliver tailor-made content related to that prior knowledge to help students to progress. Adaptive systems should also allow students who master the material to learn faster than the other students who need more time. On top of delivering content based on learners, adaptive systems can also deliver practices (e.g., quizzes) based on learners. Learning theory encourages the instructor to provide a challenge to the students with the right amount of difficulty. Adapting the difficulty levels of practices is also part of personalization. In continuously giving the right level of difficulty, the adaptive system motivates learners to continue learning and practicing without being overwhelmed or getting bored.

The technological principle behind adaptive learning is the creation of a knowledge graph. Instructors need to create a knowledge graph that illustrates how different units of concepts are interrelated and interdependent. Instructors may need to specify what is the prerequisite of one concept before moving on to the next concept. In some platforms, this knowledge graph creation is done manually. However, the emergence of Learning Analytics and Artificial Intelligence provides possible automation to this task where Learning Analytics (LA) and AI tools can generate the first draft of a knowledge graph that instructors can then modify and edit.

Another part of personalized learning is to allow students to get prompt and immediate feedback via learning analytics in synchronous learning. In this area, AI chatbot has a huge potential to deliver prompt and immediate feedback to learners. Research suggests that the role of the instructor is important in helping learners learn, think through, and find information. The development of intelligent chatbots helps learners and instructors in this process of learning. The chatbot allows learners to get information faster and in a way that is more relevant as a response to their questions rather than a list of search results. Moreover, a conversational chatbot helps learners to clarify and refine their "search" rather than just adding new keywords or applying different filters in a search engine. In this way, a conversational chatbot is a gateway for learners to get more relevant and useful information than from a search engine. One SUTD campusX initiative is about developing a chatbot that allows such personalization in giving answers and feedback to students. The chatbot becomes an interface that integrates features that allow students to learn anywhere, anytime. Instructors are notified when students ask questions, and instructors can then encourage responses from other students or review the ones generated by the AI chatbot. The ability for instructors to edit and give endorsements may impact the way students accept the response. In this way, generative AI chatbot speed up the learning dialog between students and teachers.

3.6 Learning analytics

Learning Analytics is becoming increasingly important in higher education. LA can be broadly defined as the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs [25]. Learning analytics are used with learning sciences to develop methods for working with a wide range of large datasets to optimize learning processes, outcomes, and environments, with a clear set of ethical guidelines [26]. Examples of LA techniques include the use of predictive modelling, clustering and regression analysis, feedback generation, and multimodal (e.g., video analytics) analytics. Predictive analytics is a set of techniques used to make inferences about uncertain future events [27]. Classification and regression techniques are typically used to cluster and find relations between variables [28]. LA is used to provide feedback to students, and this has shifted from purely performance-based to self-monitoring, self-regulation, and student wellness [29–31]. Video analytics can also be used to track students' faces and physical movements to study engagement [32].

Educational institutions are beginning to realize the potential of LA and are taking steps to build the LA infrastructure and capabilities. SUTD campusX is setting up a data warehouse and pipeline to integrate available data sources. Figure 6 shows an overview of the data pipeline that the analytics team is building up from various data sources including video and audio analytics. The data sources are integrated, and essential data are extracted, transformed, and loaded before it is presented in various dashboards. Through combinations of various data sources, useful and pertinent dashboards can

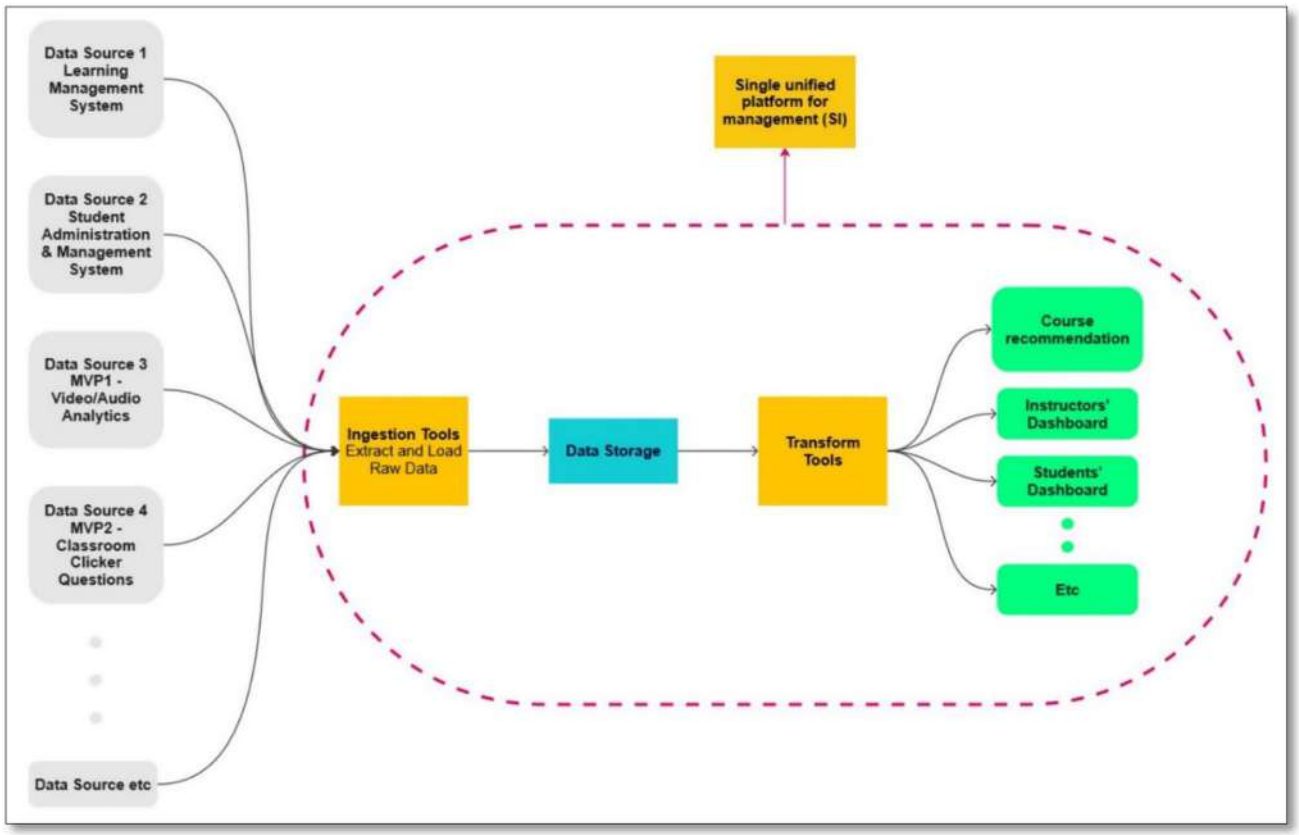

Fig. 6 SUTD campusX Learning Analytics Data Pipeline

be generated to help educators and learners improve their teaching and learning especially in real-time in an ongoing class. Together with AI-Chatbot in personalized learning, such real-time feedback via individual- or group-based analytics can be a very powerful tool in complementing the telepresence robot to enhance the learning outcome if data privacy is not compromised.

In recent years, there has been an increasing awareness of ethical issues surrounding data usage in LA [8]. Transparency in terms of what data is collected, how it is used, and the ability for students to opt in/out is a high priority. The design of campusX data pipeline architecture is influenced by these various ethical frameworks to safeguard users and ensure that necessary steps such as de-identification of data and anonymization are incorporated.

LA underpins the various campusX projects and here we give an example of how LA is used in the case of the telepresence learning system described earlier. In the telepresence learning system, video and audio data are captured. Video is streamed from the 360-camera to a serverless storage where it is stored temporarily before being fed into algorithms for video and audio analysis. For video analysis, positive and negative emotions are detected. For audio analysis, the number of audio speakers is detected. The aggregated data is then stored before it is transformed into a single engagement score. The engagement score utilizes aggregated data; hence, no unique individual can be identified from the stored tabular data. The streaming 360 video and audio data is not stored and are discarded once the tabular data has been aggregated. Thus, the only data stored are the list of emotions as well as the number of speakers. This approach not only safeguards the privacy of students but also enables ethical and effective use of analytical data to help students learn better.

The engagement score allows instructors to have an important metric to identify and observe groups who are disengaged during breakout discussions. This will then allow instructors to intervene appropriately in real time. Students will then be able to benefit from the instructor's guidance. Another plan is to create flexibility in allowing personal "live" LA to be provided to individual users via a self-selection option. Such personal data which will not be seen by others including instructors is useful in alerting or drawing student's attention back to the class participation in real-time. Figure 7 shows the analytics deployed in the telepresence learning system.

Some findings from the various pilot studies of the telepresence learning system and learning analytics are that instructors were able to intervene more actively and promptly due to the real-time nature of the engagement score. There was

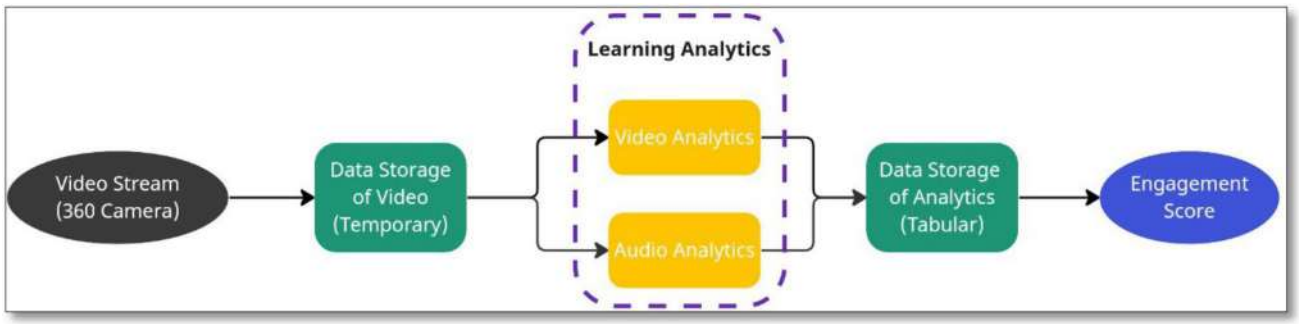

Fig. 7 Learning Analytics Architecture for Telepresence Learning System

also a higher conversion of disengaged to an increase in engagement after the instructor's intervention based on the engagement score. Thus, LA seems to have a lot of potential in providing effective real-time feedback to aid teaching and enhance learning in-situ during a class.

We plan to scale up the learning analytics platform by also examining the reliability of the engagement score. Apart from the video and audio analytics mentioned, we further plan to study students' attendance, engagement, understanding, and personalized feedback using LA. We are also building instructor and student dashboards for grades overview, personalized feedback, and early intervention alerts. These are the planned milestones that will be gradually introduced to the instructors and students of SUTD to support their teaching and learning.

4 Discussion

SUTD campusX takes a holistic perspective of teaching and learning, from building the learning environment for both cyber and physical and students to developing the technology tools, building the analytics warehouse and architecture, examining instructional design, and delivering the lessons. This can be seen in the application of the innovation learning spaces (Living Labs) to develop a CPL environment through the innovation of the telepresence learning system, immersive metaverse/gamification platform, personalized learning pathways, and learning analytics.

The setup of SUTD campusX involves over 70 faculty and staff members who are specialists and experts in various fields, such as teaching STEAM subjects, learning sciences, and emerging technologies. Such a setup involves both top-down and bottom-up support from senior leadership and ground level. One key advantage of such functional and diversified group of members is the rapid formation of cross-disciplinary teams consisting of members from different areas to tackle challenging pain points or issues. The campusX teams aim to innovate teaching in terms of both technology and pedagogy/andragogy, advance knowledge in CPL for student-centered learning, and build the community of practitioners in CPL. To this end, SUTD campusX is building local and international alliances to offer platforms for sharing experiences in designing, developing, and evaluating CPL in various institutions. For better outcomes, the projects are conducted in integrated teams and discussed through regular meetings so that the various teams are kept informed of the project progression and developments to gain a holistic understanding of the interactions and implications of the various innovation streams. Teams interact, discuss, and offer ideas actively to improve and overcome the challenges encountered. A community setup (both internationally and locally) provides support in refining the design, development, and evaluation of technology and pedagogy/andragogy. Overall, SUTD campus initiative provides the required support and framework for championing efforts to realize CPL. Since it can be challenging to change the educational system within a university, the strategy is to experiment in an iterative manner to keep improving and scaling up in an evidence-based manner, being informed by literature and learning theories but grounded by findings from field user trials.

4.1 A pragmatic development approach: MVP Proof-of-concept to Practice (P2P)

To translate from "Proof-of-Concept (PoC)" to "actual practice/implementation" (i.e., actual classes with actual students for rapid development or finetuning of teaching and learning practices) in a timely and appropriate manner, campusX adopts a pragmatic 4-stage project development and translation approach. The Proof of concept is developed through a Minimum Viable Product (MVP) process. This involves several iterations of.

- Design-thinking workshops with users to identify barriers and challenges in teaching and learning
- Formulation of functional requirements from the identified barriers and challenges
- The functional requirements form the required features to be developed under the minimum viable product (MVP)

Once MVP functionalities are established and a first prototype is developed, a small-scale trial of the MVP is conducted in simulated classes with small groups of students on ungraded/non-credit activities. For example, the Telepresence Learning System was tested by a group of SUTD undergraduates (physical) and overseas students (cyber) from two university partners in China under an SUTD student mobility program. Thereafter, the functionalities were further tested by a group of undergraduate and graduate students at SUTD campus. From these user trials, the design of the MVP was quickly validated, and further improvements were identified. An innovation space with settings that are similar to an actual classroom (like the Living Labs) will be an ideal place to conduct such trials. This allows us to conduct larger-scale trials of the MVP in an actual class environment with a longer duration using actual students (undergraduate, graduate, and CET). To encourage adoption, it is advisable that such lessons be conducted with no implication on grade and GPA first.

The final phase is the "production" mode (i.e., the full implementation of the MVP). This will be adopted into real classes with actual students and has real consequences on the learners, e.g., affecting grades and GPA. Close-loop feedback must be adopted to enhance and finetune the pedagogy/andragogy, so that positive learning outcomes are achieved.

Under the above "MVP Proof-of-Concept to Practice (MVP P2P)" framework, MVPs will be developed, tested, revised, or terminated depending on student and instructor feedback with rapid turnaround speeds. Unlike typical technology development research, the MVP P2P approach will deliver much faster and practice-oriented innovations for educators and learners to meet their real needs.

We believe that the learning experience of students and teaching experience of instructors are important, and so we leverage on SUTD "Design-thinking and innovation" philosophy to explore innovative "Technology of Learning (ToL)" under the MVP P2P framework to have rapid prototyping of tools and systems to bring to classrooms quickly. We envision launching the developed MVPs to perform trial runs at actual classes in Academic Year 2025/26, starting with freshmen year students and then progressively progressing to junior and senior year students. Through this pragmatic approach, SUTD aims to realize a cyber-physical campus for PET and CET learners by 2030. Our aim is to scale various educational and design innovations under campusX to support learning and teaching at the national level across Singapore.

4.2 Cyber-physical learning alliance

To realize campusX cyber-physical learning requires significant resources as it involves complex integration involving technology, pedagogy/andragogy, ethics of learning, user trials, data governance and privacy, etc. Future CPL education will need to leverage on expertise from various academic partners to collaborate and jointly develop more robust and user-oriented solutions. Recognizing that collective strength is needed, an international and national Singapore Cyber-Physical Learning Alliance (CPLA) has been formed to pool expertise and resources within and outside Singapore, with the common aim to work together to advance and promote Cyber-Physical Learning. The international alliance, together with the Singapore University of Technology and Design (SUTD), consists of the following academic institutions:

- Aalto University, Finland
- Zhejiang University, China
- Hong Kong University of Science and Technology, Hong Kong
- Tecnológico de Monterrey (Tec), Mexico

The local alliance consists of the following academic institutions:

- Singapore University of Social Sciences (SUSS)
- University of Arts Singapore: LASALLE College of the Arts (LASALLE)
- University of the Arts Singapore: Nanyang Academy of Fine Arts (NAFA)
- Institute for Adult Learning (IAL)
- Ngee Ann Polytechnic
- Singapore Ministry of Education (as an observer)

Together, the CPLA members aim to collaborate on joint projects to realize cyber-physical learning (such as conducting projects on research/innovation, scholarship, and field experiments of cyber-physical learning); evaluate instructional design, pedagogies/andragogies, and learning effectiveness of cyber-physical courses; disseminate and share knowledge and expertise of cyber-physical learning among alliance members; examine and promote the adoption of cyber-physical learning internally within their institutions; and promote the benefits and advantages of cyber-physical learning to internal and external audiences (across academia, industry, media, and government).

5 Conclusion

We have shared the CPL approach of SUTD and presented the vision and philosophy of SUTD campusX, followed by illustrating how the projects of campusX enable an adaptive and personalized future of education at SUTD. There are challenges in realizing CPL in terms of acceptance by users (educators and learners), competency of users to be conversant in CPL technologies, and in the context of SUTD curriculum, the high proportion of hands-on and collaborative group-based learning. To address these challenges SUTD has applied a pragmatic approach towards developing its suite of CPL technologies using the MVP P2P framework to do rapid and validated translation to practice. Another approach is to harness the collective expertise and resources of like-minded partners by forming a Cyber-Physical Learning Alliance to conduct joint innovations and user trials to advance CPL. Given today's VUCA world, it is important that continual improvements to teaching and learning are undertaken to address the future needs of education. We believe that SUTD campusX is one such initiative in addressing the Future of Education through Cyber-Physical Learning.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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