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We are pleased to share with our readers the results of the annual evaluation of the ERIES Journal in the SCImago Journal & Country Rank. In the 2025 edition, the ERIES Journal was again ranked in Q3 in the Education category, with an SJR of 0.336, compared with 0.356 in 2024. Although the SJR value shows a slight decrease, broader citation indicators point to a clear upward trajectory. External citations per document increased by 22.6%, from 1.562 in 2024 to 1.915 in 2025. Total citations rose by 14.6%, reaching 157, compared with 137 in the previous year. At the same time, self-citations decreased sharply, from 23 to 6, representing a reduction of 73.9% and indicating stronger external recognition of the journal's published work. Citations per document within the three-year window also improved modestly, from 1.877 to 1.915, confirming steady growth in impact.

Based on these indicators, the ERIES Journal was evaluated as the leading journal in the Education category in the Czech Republic, where none of the ten journals listed in this category is ranked in Q2 or higher. The journal also ranked 20th out of 114 journals in the Education category across Eastern Europe. These results confirm the journal's strengthening position in the global landscape of education research, as well as its growing visibility, credibility, and international recognition. This positive trajectory reinforces our commitment to publishing content of the highest quality.

In this second issue of 2026 (Vol. 19, No. 2), we are pleased to present six articles from diverse regions, including India, Indonesia, the Czech Republic, and Hungary. Together, they examine how education systems respond to the challenges of innovation, creativity, and student development in rapidly changing contexts. The contributions address a wide range of topics: curriculum reform in architectural design education, the mapping of critical thinking skills among junior high school students, the mediating role of digital creativity in educational management systems, the integration of AI into inquiry-based mathematics learning, the quality attributes of online professional development for teachers, and the impact of serious management games on students' mood and learning in project management. Despite their varied settings, these studies converge on several central themes: the importance of aligning curricula and practices with global standards, fostering creativity and higher-order thinking, using digital tools responsibly, and ensuring that educational innovation translates into improved student outcomes and professional growth. Collectively, they highlight the ongoing transformation of education towards efficiency, responsibility, and adaptability in the 21st century.

In the first article, "*Reviewing Architectural Design Education (ADE) in India: Curriculum Analysis and a Proposed Competency Assessment Framework*", Elizabeth Jerome and Shreya Maulik from Atlas SkillTech University, India, examine the current state of architectural design education and its alignment with international standards. The study shows that ADE curricula in India have remained largely unchanged for two decades, with a strong focus on theory and design skills but limited integration of new technologies and practical experience. By comparing Indian curricula with frameworks developed by international bodies such as NAAB, RIBA, and AIA, the authors identify discrepancies in standards and gaps between regulatory expectations and implementation. To address these challenges, they propose the PREDICT competency assessment framework, which comprises six domains: Professionalism and Lifelong Learning, Research and Critical Analysis, Ethics and Social Responsibility, Design Thinking and Innovation, Communication and Collaboration, and Technical Proficiency. This framework aims to bridge gaps in industry readiness, creativity, teamwork, and technical skills, thereby aligning Indian ADE more closely with global practices and enhancing graduates' preparedness for real-world challenges.

In the second article, "*A Dimensional Analysis of Junior High School Students' Critical Thinking Skills*", Wayan Redhana and colleagues from six Indonesian universities, together with Mohd Shahril Nizam bin Shaharom from Universiti Malaya, Malaysia, present a provincial-level study of 403 junior high school students in Bali. Using a content-free CTS test with high reliability, the authors mapped students' abilities across evaluation, interpretation, analysis, inference, and explanation. The findings reveal that overall mastery of CTS remains low, with average scores below 60%. Evaluation and interpretation emerged as relatively stronger dimensions, whereas analysis and explanation were consistently weaker, reflecting instructional practices that emphasise memorisation over reasoning and reflection. The study situates these results within both national and international contexts and notes that limited CTS development is a systemic challenge. The authors argue that strengthening CTS requires problem-based and project-based learning, together with assessments that enable students to articulate their reasoning and defend arguments. At the policy level, the findings reinforce the importance of implementing Indonesia's Independent Curriculum in ways that genuinely promote higher-order thinking.

In the third article, "*The Mediating Role of Digital Creativity in the Relationship Between Attitudes Toward Digitalization and Educational Management Information Systems*", Farida Farida, Jamal Fakhri, Andi Thahir, Ahmad Fauzan, and Suherman Suherman from Universitas Islam Negeri Raden Intan Lampung, together with colleagues from Hungary, explore how user attitudes and creativity influence the success of Educational Management Information Systems (EMIS). Based on survey data from 347 respondents and using Structural Equation Modelling, the study tested four hypotheses linking attitudes toward digitalisation (ATD), digital creativity (CTD), and EMIS performance. The findings show that ATD directly enhances EMIS effectiveness and indirectly strengthens it through CTD, which emerged as a critical mediator. While positive attitudes provide the motivational foundation for technology adoption, creativity transforms these attitudes into innovative and responsible applications. The authors emphasise that successful EMIS implementation requires supportive organisational cultures that foster experimentation, flexibility, and creative problem-solving. By cultivating both attitudinal readiness and creative capacities, institutions can ensure that EMIS functions not merely as an administrative tool but also as a dynamic driver of efficiency and educational improvement.

In the fourth article, "*Evaluating the Impact of AI-Supported Inquiry-Based Learning on Students' Creative Mathematical Performance, Critical Problem-Solving Skills, and Attitude toward Mathematics*", Mujib Mujib, Suherman Suherman, and Mardiyah Mardiyah examine how artificial intelligence can enhance inquiry-based mathematics instruction. Using a quasi-experimental design, the study compared students taught through AI-supported inquiry-based learning with those receiving conventional instruction. The results show significant improvements in creative mathematical performance and attitudes toward mathematics among students in the experimental group, with the strongest gains observed in motivation and engagement. Students demonstrated greater originality and flexibility in generating solutions, suggesting that AI tools can scaffold exploration and foster divergent thinking. However, no statistically significant improvement was found in critical problem-solving skills, indicating that higher-order reasoning requires more sustained scaffolding and metacognitive guidance. The authors conclude that integrating AI into inquiry-based pedagogy can strengthen creativity and affective development in mathematics education, provided that digital tools are complemented by teacher facilitation and supportive classroom environments.

In the fifth article, "*What Makes Online Professional Development Work? Unpacking Quality Attributes and Their Impact on Teacher Satisfaction and Professional Practice*", Mohamad Arief Rafsanjani, Waspodo Tjipto Subroto, Luqman Hakim, and Handri Dian Wahyudi investigate the effectiveness of online professional development (PD) for teachers in Indonesia. Drawing on survey data from 247 economics teachers and applying structural equation modelling, the study identifies three attributes that establish the quality of online PD: collaboration, cognitive activation, and clarity and structure. The findings show that these attributes significantly enhance teacher satisfaction and contribute to changes in professional practice, confirming the relevance of the Community of Inquiry framework and the Kirkpatrick model for evaluating training programmes. Online PD was found to be effective in strengthening pedagogical knowledge and teaching practice, while offering advantages of accessibility and efficiency compared with traditional formats. The authors conclude that ensuring social presence, cognitive presence, and teaching presence is essential for successful online PD. They recommend that providers and policymakers integrate these elements to support continuous teacher growth, particularly for educators who face barriers to offline participation.

In the sixth article, "*Mood States and Student Learning in Project Management: Validating and Extending Prior Research with New Data*", Josef Kunhart, Simona Huguet, and Jan Bartoška from the Czech University of Life Sciences Prague examine the effects of serious management games on students' mood and learning outcomes in project management seminars. Conducted between 2023 and 2025, the study applied the Profile of Mood States method to evaluate changes in total mood and individual factors during waterfall and agile seminars. Across all years, students' total mood improved significantly, with reductions in fatigue, depression, and confusion, while tension decreased in most cases. The findings confirm the positive impact of practical seminars on teamwork, communication, and soft-skills development, and validate earlier results using larger datasets. Minor differences between years, such as changes in seminar themes, highlight the importance of continuous refinement in instructional design.

The authors conclude that serious management games consistently enhance student mood and engagement and propose extending this research to diverse contexts, institutions, and languages to broaden its applicability.

We extend our sincere gratitude to all authors who contributed their research to this issue of the ERIES Journal and to our reviewers for their dedicated efforts in ensuring the quality of the published work. Their commitment and expertise are essential to maintaining the journal's standards of excellence. We hope that readers will find this second issue of the year both insightful and inspiring. To stay connected with the latest updates, including our most cited articles, upcoming events, and calls for special issues, we invite you to follow the ERIES Journal on LinkedIn.

Sincerely

Martin Flégl
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CONTENT

Full research paper

REVIEWING ARCHITECTURAL DESIGN EDUCATION (ADE) IN INDIA: CURRICULUM ANALYSIS AND A PROPOSED COMPETENCY ASSESSMENT FRAMEWORK

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ABSTRACT

Architectural Design Education (ADE) in India has changed little over the past two decades and still relies on an outdated curriculum. As a result, students and graduates may be underprepared for real-world professional challenges. Previous research from Europe, the USA, India, Australia, and South Asia shows considerable variation in ADE curricula, which generally fall into two areas: art and design, and technical practice. This study examines the curricular focus of Indian and international universities, compares frameworks developed by Indian regulatory bodies such as COA and AICTE with those of NAAB, RIBA, and AIA, and evaluates how closely Indian university curricula align with these standards. By comparing five leading architecture schools in India with four international institutions, the study identifies both shared features and major differences. The findings show that Indian ADE emphasises foundational theory and design skills but pays less attention to emerging technologies and practical experience than international programs do. The study also reveals gaps between COA standards and their implementation. In response, it proposes a competency assessment framework to support curriculum standardisation, improve assessment efficiency, and promote consistency and accountability.

KEYWORDS

Architectural Design Education, comparative analysis, competency assessment framework, curriculum alignment, efficient assessment, regulatory bodies

HOW TO CITE

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Highlights

- *Proposes a standardised competency assessment framework for undergraduate architecture education.*
- *Aims to reduce ambiguity in assessments among students, academics, and recruiters.*
- *Aims to enhance efficiency through streamlined and measurable assessment criteria.*
- *Promotes responsible and transparent educational evaluation practices..*

INTRODUCTION

The field of architecture evolves in response to socio-cultural, economic, and technological advancements, which require regular updates to curricula and competency lists (Şengül Erdoğan et al., 2021). Architectural Design Education (ADE) in India is governed by the Council of Architecture (COA), which enforces standards, regulates the curriculum and competency framework, and ensures quality education for students. Despite this, ADE in India faces significant challenges in balancing theory and practical skills (Bhattacharjee and Bose, 2015). In this study, ADE refers to the educational framework through which architectural design knowledge (K), skills (S), attributes (A), and professional thinking are developed within architecture institutions through curriculum content, evaluation methods, and professional preparation.

Education–practice divide in ADE

Early architecture schools in India placed strong emphasis on skill and craft development. However, they gradually evolved to follow the Vitruvius and Bauhaus models (Bhattacharjee and Bose, 2015; Jerome and Maulik, 2024). Even today, remnants of these international influences can be seen in the curriculum.

Although the architectural community continues to discuss whether the traditional educational model should change to better prepare students for the demands of practice, ADE in India has largely remained unchanged for an exceedingly long time (Jerome and Maulik, 2024). Since the 1960s, industry professionals and design faculty have strongly criticised the Bauhaus educational approach, which drew a clear distinction between theory and practice (Jerome and Maulik, 2024; Hejazi and Shafaei, 2020). The division of academic preparation into "education" and "practice training" is based on this distinction between theory and practical skills. Education gives students the tools to think critically, conduct research, and solve complex present and future problems, whereas training provides the technical and analogue skills required by the industry and facilitates employment opportunities (Frascara, 2020; Jerome and Maulik, 2024).

A review of previous research in India and elsewhere indicates substantial variation in ADE curricular focus, ranging from an art and design focus (core academic theory) to technical aspects and professional practice (Bhattacharjee and Bose, 2015). However, previous research does not clarify the extent of curricular change required to achieve standardisation and better prepare students for real-world practice. Articulating the anticipated extent of change is therefore an important first step, alongside the active involvement of students, practitioners, and academics (Corvalán et al., 2015). In addition, there is a mismatch between two key stakeholder groups—academics and practitioners—regarding the knowledge, skills, and attributes (KSAs) expected of architecture graduates by practitioners and those perceived to be acquired through academia (Hejazi and Shafaei, 2020; Shannon, 2012; Garg et al., 2022; Jerome and Maulik, 2024). This further confirms the gap between architectural education and professional practice, with both domains being viewed as separate entities by stakeholders.

ADE in the global and Indian context

Architectural education faces global challenges. Many countries recognise that curricula and teaching methods are outdated and require revision (Lee, 2018; Maneshi et al., 2023; Soliman et al., 2019).

Key issues include:

- gaps between theory and practice (Corvalán et al., 2015; Maneshi et al., 2023; Soliman et al., 2019; Lee, 2018);
- disconnects between industry and academia (Maneshi et al., 2023; Soliman et al., 2019);
- undefined skill sets for professional practice (Maneshi et al., 2023; Soliman et al., 2019; Lee, 2018);
- inadequate practical training for students (Maroya et al., 2019; de Boissieu and Deutsch, 2022; Komnenic et al., 2016; Hejazi and Shafaei, 2020; Garg et al., 2022); and
- insufficient coverage of industry-relevant skills. Critical thinking and strategic analysis are essential academically, while practical skills such as entrepreneurship, budgeting, marketing, design production, business planning, technical knowledge, and communication are crucial for industry readiness (Bhattacharjee and Bose, 2015; Corvalán et al., 2015; Maneshi et al., 2023). Current curricula do not effectively cover these skills, which may leave students less prepared for the workforce (Maneshi et al., 2023; Soliman et al., 2019).

Architectural education in India expanded significantly in the early 20th century (Bongirwar and Das, 2022). The first organised architecture course began at Sir J. J. School of Art in Mumbai in 1913 and was influenced by European styles and traditional teaching methods (Bongirwar and Das, 2022). COA regulates the curriculum, combining theory, practical studies, and project work (Bhattacharjee and Bose, 2015). However, the insufficient integration of modern technologies and methodologies has been criticised (Bongirwar and Das, 2022; Naralasetty and Ugrani, 2023).

Current challenges point to the need for reform, as outdated curricula and teaching methods do not adequately address rapid technological advancement (Pandit, 2019). Graduates are often underprepared for real-world employment and may later return as educators, raising concerns about the effectiveness of the education provided (Bhattacharjee and Bose, 2015; Chandavarkar, 2018). Moreover, the disconnect between academia and industry (Yamano and Iba, 2024) limits collaboration and creates a disparity between classroom-based skills and professional needs. Reforms should align programmes with international standards, enhance practical training, and encourage students to engage critically with current architectural challenges in order to develop creative problem-solving abilities (Chandavarkar, 2018).

Role of regulatory bodies in ADE: India vs. international context

As Table 1 shows, the regions considered in the comparative analysis of regulatory bodies are the UK, the USA, India, and Australia.

COA is primarily responsible for overseeing architectural education in India by accrediting institutions, establishing curriculum frameworks, and certifying compliance with educational standards (Bhattacharjee and Bose, 2015; Bongirwar and Das, 2022). However, the rigid framework of COA and the All India Council for Technical Education (AICTE), which has remained largely unchanged since 1983, has been strongly criticised for its inability to keep pace with evolving industry needs and educational demands (Bhattacharjee and Bose, 2015; Chandavarkar, 2018). Conversely, global accreditation bodies such as Royal Institute of British Architects (RIBA) and National Architectural Accrediting Board (NAAB) use active approaches involving regular reviews, stakeholder engagement, and robust quality assurance mechanisms to ensure that programmes meet contemporary challenges (Bentley, 2013; Bhattacharjee and Bose, 2015). Unlike COA, these organisations prioritise multidisciplinary perspectives and technology integration, enabling a more effective response to global and industry demands (Bentley, 2013; Chandavarkar, 2018).

Role of technology in architectural education: India vs. global context

Technology has a major influence on ADE in India and globally, although its integration and implementation vary. In India, technological integration is reported to be slow and inconsistent because of a heavy reliance on traditional teaching methods and regulatory frameworks that hinder rapid change

Accreditation Board	Region	Key Points	Curriculum Regulation
Royal Institute of British Architects (RIBA)	United Kingdom	-Validates architecture programs through peer reviews. - Focuses on quality and student performance rather than credit hours. - Requires internal validation reports and external examiners' reports. - More flexible timelines and less paperwork compared to NAAB.	Curriculum is informed by the Education General Criteria (EGC) without setting specific credit hour requirements, allowing flexibility while emphasizing design quality.
National Architectural Accrediting Board (NAAB)	United States	- Accredits architecture programs leading to licensure in the USA. - Requires 150 credit hours with defined core areas, ensuring a structured approach to education. - Needs programs to submit a formal letter and a Plan for Achieving Initial Accreditation along with proof of institutional accreditation.	Defines specific Student Performance Criteria (SPC) that programs must meet, ensuring that the curriculum aligns with required competencies and skills needed for practice.
Council of Architecture (COA)	India	- Regulates architectural education standards in India. - Enforces curriculum standards and guidelines for architectural programs.	Sets minimum requirements for curriculum structure, including courses in design, history, technology, and practical training, aligning with national education goals.
Australian Institute of Architects (AIA)	Australia	- Sets criteria touching upon design studies, documentation, history, practice management, and communication skills for architects.	Guidelines dictate the integration of the various key elements into the educational curriculum, ensuring that programs align with industry needs and standards.

Table 1: Comparative analysis of global regulatory bodies in architecture

(Pandit, 2019; Bongirwar and Das, 2022; Naralasetty and Ugrani, 2023). This variation affects students' preparedness for technology-driven jobs and, consequently, their employability. Globally, many architecture schools integrate technology into their curricula to enhance students' employability skills and adaptability to the professional world (Hammadamin and Nordin, 2024; Soliman et al., 2019). Regions such as North America, Europe, the Middle East, and South Asia have integrated technologies such as virtual reality (VR), augmented reality (AR), and advanced modelling techniques into ADE, creating dynamic learning environments (Bhattacharjee and Bose, 2015; Bentley, 2013). In contrast, emerging technology research in Indian architecture is recognised but limited by funding, resources (Bhattacharjee and Bose, 2015; Chandavarkar, 2018), and, more importantly, resistance to adopting new approaches. Global architecture schools extensively research technological integration and innovation in design (Bhattacharjee and Bose, 2015; Soliman et al., 2019). Overall, technological integration in ADE varies significantly between India and global institutions.

Role of existing competency frameworks

Existing studies in art and design, engineering, and science education examine rubrics and competency frameworks (Lutnæs, 2018; Pop-Iliev and Platanitis, 2008; Allen and Tanner, 2006). Rubrics provide clear and organised frameworks for defining and evaluating competencies in education. However, in design education, skills such as creativity, collaboration, and critical thinking, although increasingly recognised as essential learning outcomes, often remain underrepresented (Lutnæs, 2018). Rubrics should make learning goals and evaluation criteria unambiguous for all stakeholders, including students, teachers, and recruiters, thereby bridging the gap between expected and acquired competencies, especially in creative educational tasks (Allen and Tanner, 2006). In Norwegian art and crafts education, one study highlighted that rubrics were commonly used to assess craftsmanship and students' technical skills, emphasising competencies such as "developing techniques" and "crafting and improving" (Lutnæs, 2018). The rubric used was a flexible, non-linear, and open-ended framework that enabled evaluators to assess creativity in student performance by accommodating various interpretations and expressions in design education and by aligning with a disciplined, practice-based understanding of creativity.

Another relevant study by the Centre for Real-World Learning (CRL) developed the Creativity Wheel, which identifies five core creative tendencies: inquisitive, persistent, imaginative, collaborative, and disciplined. Each tendency includes sub-tendencies that frame creativity as an assessable competency (Pop-Iliev and Platanitis, 2008). The rubric uses a performance-level scale and functions as a structured assessment tool with defined performance criteria, allowing engineering students' design projects to be assessed systematically. Many educators face challenges in evaluating and assessing creativity. Creativity is often framed as an innate trait rather than a skill that can be developed, leading to vague or inaccurate assessment. In addition, an overemphasis on individual performance can overshadow the collaborative competencies that are crucial in real-world problem-solving. To address these challenges and gaps, a new, more holistic framework is needed to integrate the identified gaps and reduce ambiguity.

An exhaustive literature review identified multiple recurring research gaps. Across regions, the identified gaps emphasise four key aspects:

1. Disconnect between theoretical knowledge and practical application
2. Variation in curriculum content, depth, and focus
3. Ineffective assessment techniques
4. Lack of practical training or real-world experience

Taken together, these gaps highlight the need for a standardised curriculum framework that can benefit universities. A limited number of studies have been conducted in India to identify the gaps and difficulties in ADE and practice at the local, state, and national levels (Jerome and Maulik, 2024). Further research is therefore essential for addressing these challenges and developing a more effective and efficient ADE system that equips students with the knowledge, skills, and attributes needed to address the complex challenges facing the built environment in the 21st century.

Therefore, the main objective of this study is to identify and highlight the commonalities and differences in curriculum structures and competencies required by architecture graduates globally and within India, thereby contributing to a more efficient, standardised, and responsible approach to competency development and evaluation in architectural education.

MATERIALS AND METHODS

The paper uses a comparative analysis method (as seen in Figure 1) to examine the ADE curricula across five premier architecture schools in India and four architecture schools globally, compare global regulatory bodies, and assess the alignment between architecture schools in India and the KSAs defined by the regulatory body in India.

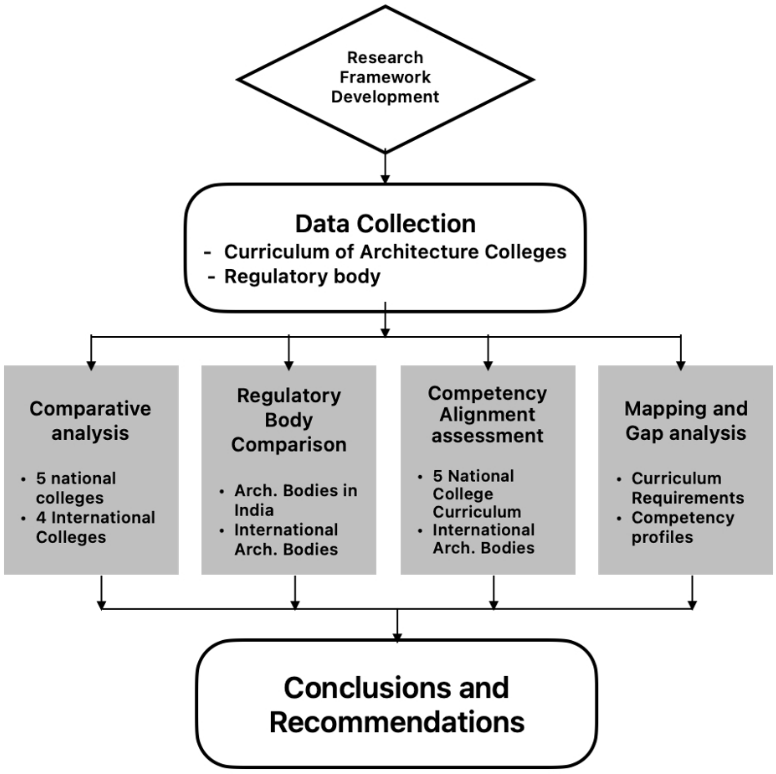

Figure 1: Research methodology framework

Data analysis technique

The analysis was performed through three lenses: the curricular focus of Indian universities compared with that of international universities; the curriculum framework established by Indian regulatory bodies such as COA and AICTE compared with that of international regulatory bodies such as NAAB, RIBA, and AIA; and the alignment of curricular focus between universities and regulatory bodies in India.

The criteria for curriculum evaluation were identified as the breadth and depth of courses, the balance between theory and practice, integration across disciplines, curricular focus, course alignment with learning outcomes, and learning outcome alignment with competency. They are defined as follows:

- Breadth and depth of courses - the relationship between core and optional content, analysed through the subjects covered and the number of contact hours allocated.
- Balance between theory and practice - the extent to which the curriculum is dedicated to theoretical learning versus studio-based practical education and the engagement of practising professionals as instructors.
- Integration across disciplines - how well different fields, such as urbanism, construction, and the humanities, are integrated into architectural education to ensure a holistic learning experience.
- Curriculum focus - the main areas of emphasis within the educational programme and the extent to which the core concepts of architecture are prioritised and effectively conveyed across courses.
- Course alignment with learning outcomes - how individual courses are structured to meet specific educational objectives and how the content taught aligns with students' desired competencies.

- Learning outcome alignment with competency - how the defined learning outcomes correspond with the competencies expected from graduates and the extent to which the educational programme prepares students for professional practice.

The architecture schools in India were identified using the National Institutional Ranking Framework (NIRF) rankings of 2023 and included the Indian Institute of Technology (IIT) Roorkee, the School of Planning and Architecture (SPA) Delhi, Nirma University Ahmedabad, the National Institute of Technology (NIT) Calicut, and Kamla Raheja Vidyanidhi Institute for Architecture (KRVIA). The international architecture schools were identified based on the QS World University Rankings and consisted of the Bartlett School of Architecture at UCL, Massachusetts Institute of Technology (MIT), the National University of Singapore (NUS), and Royal Melbourne Institute of Technology (RMIT) Melbourne.

The analysis was conducted through a structured, multi-stage process designed to ensure systematic and fair interpretation and comparability. The comparative analysis for each parameter was performed using the following process:

a) Official curriculum and regulatory body documents from selected institutions and regulatory bodies were critically reviewed and summarised to extract key themes, concepts, and terminology relevant to architectural education.
b) The key points were used to generate word clouds, enabling a visual representation of dominant curricular emphases.
c) The frequency of individual terms within the word clouds was analysed to identify patterns and relative prominence across curricula.
d) The observed word frequencies were mapped onto a Likert-scale framework, as shown in Table 2 (Shannon, 2012), to translate qualitative textual data into a comparable semi-quantitative measure. A frequency score of 5 indicates a dominant presence of repeated keywords, whereas a score of 1 refers to a very low presence of repeated keywords. Keywords and thematic categories were refined iteratively through repeated reading.

Frequency Score	Label	Frequency Pattern Description
5	Very High Frequency	Dominant presence of keywords (≥ 12 occurrences) Multiple high-frequency clusters (≥ 10 each). **Shows extremely strong emphasis in the dataset**
4	High Frequency	Key terms appear very frequently (8–11 occurrences). **Clear emphasis but not overwhelming**
3	Moderate Frequency	Medium-level presence (5–7 occurrences). **Balanced emphasis but not dominant**
2	Low Frequency	Infrequent appearance (2–4 occurrences). **Indicates presence but low emphasis**
1	Minimal Frequency	Very low appearance (1–2 occurrences). **Indicative of weak or negligible emphasis**

Table 2: Frequency rating system (Likert Scale Explanation) (modified and adapted from Shannon, 2012)

The final process for developing the proposed framework was structured to ensure clarity and consistency in competency identification and evaluation. The use of standardised indicators improves reproducibility and reduces evaluator subjectivity, thereby contributing to more responsible assessment practices.

RESULTS

This section highlights key insights from previous literature, compares the curricula of premier architecture schools in India and globally, and compares these curricula with global architecture regulatory bodies. In addition, it examines the alignment between Indian architecture schools and the graduate competencies—knowledge, skills, and attributes—defined by COA.

Comparison between Indian and international architecture schools

Analysis of the curricula from the Bartlett School of Architecture, MIT, RMIT, and the National University of Singapore (NUS) highlights their shared focus on integrating theory and practice, while each institution adapts this focus to its own goals and principles. Bartlett blends creative exploration with technical precision through studios and technical modules, strongly emphasising spatial dynamics, sustainability, and user experience. MIT implements an interdisciplinary approach, combining design, theory, computation, and environmental systems to address global issues, with a focus on innovation and technical mastery. RMIT adopts a design-led model with projects emphasising urbanism, sustainability, and problem-solving in civic and urban design, while electives enhance digital fluency. NUS focuses on tropical, sustainable, and systems-oriented design, integrating urbanism and computational proficiency in scale-sensitive studio projects.

Architecture schools in India show varied curriculum structures that reflect distinct thematic priorities and strengths. SPA Delhi emphasises sustainability and interdisciplinary learning, offering professional training, hands-on studio work, and elective clusters ranging from smart cities to biomimicry. NIT Calicut integrates technology and sustainability through construction labs, workshops, and electives such as architectural journalism and smart cities. IIT Roorkee combines technical and computational design knowledge with real-world exposure through internships and innovative courses such as industrialised construction and housing. Nirma University focuses on urban planning, heritage, and applied research alongside field studios and law and management collaborations. KRVIA adopts a regional and critical design approach, promoting iterative processes and electives rooted in urbanism, society, and sustainability (Modabber Dabagh, 2019; Dupre, 2021). Key gaps include inconsistent integration of theory and practice, uneven flexibility in academic pathways, and limited embedding of BIM and AI into core modules. Although sustainability features prominently, its application lacks depth in hands-on projects. Digital tools are offered as electives rather than core learning, leading to gaps in universal digital literacy. Professional readiness also varies significantly, with some schools emphasising conceptual development (KRVIA) and others focusing on industry alignment (NIT Calicut, IIT Roorkee). Entrepreneurial exposure and structured networking remain underdeveloped. Similarly, the balance between global and local trends is inconsistent: SPA Delhi and KRVIA prioritise vernacular architecture, whereas others focus on digital transformation (Dupre, 2021).

This section compares curriculum frameworks across Indian and international architecture schools by summarising official institutional documents to identify key themes relevant to architectural education. These points were used to create word clouds that visually emphasise the main curricular highlights, as shown in Figure 6 in the Appendix. Analysis of term frequencies within these clouds revealed patterns and relative importance across curricula. These frequencies were then mapped onto a Likert scale, translating qualitative textual data into a semi-quantitative measure for easier comparison, as shown in Table 3. The Likert-scale rating emphasises thematic prominence.

Aspect	International Schools	Indian Schools	Reason
Balance between Theory and Practice	5	5	Both strong. Internationals use real-world challenges in studios; Indian schools formalize through internships.
	Seamless integration in design studios and real-world challenges.	Strong through internships, working drawings, and thesis; more formalized.	
Curriculum Focus	5	4	Internationals focus on innovation/global-local themes; Indian schools lean more technical and regional.
	Innovation, sustainability, global-local integration, cultural depth.	Technical grounding with emphasis on sustainability, urbanism, and regional relevance.	
Courses	4	3	Both include design and technical courses, but internationals offer broader and integrated approaches.
	Well-rounded mix: design, theory, environmental systems, computation.	Studio-led with technical, structural, and environmental emphasis; often semester-wise split.	
Integration across disciplines	5	3	International schools are highly interdisciplinary; Indian ones integrate via electives but to a lesser degree.
	Highly interdisciplinary links to computation, science, urban planning.	Integrated through electives in law, planning, management, and humanities.	
Course Alignment to Learning Outcomes	5	3	International programs are globally outcome-driven; Indian ones well-structured, more practice-oriented.
	Strong focus on global awareness, design mastery, sustainability, and innovation.	Well-structured outcomes emphasizing professional preparedness and digital proficiency.	
Learning Outcomes Alignment to Competencies	4	3	International: ethics + sustainability + culture. Indian: strong technical/design focus with societal impact.
	Emphasizes cultural insight, ethics, sustainability, and technical excellence.	Focus on design skills, technical adaptability, analytical thinking, and societal impact.	

Table 3: Comparative analysis of national and international architecture schools based on curriculum frameworks

Table 3 shows that international architecture schools score slightly higher across all parameters, including the balance between theory and practice, curricular focus, integration across disciplines, course alignment with learning outcomes, and learning outcome alignment with competencies. National architecture schools display a strong grounding in students' professional preparedness but lag somewhat in aligning courses with learning outcomes and competencies, even as they attempt to maintain a strong balance between theory and practice (All India Council for Technical Education, 2019; Council of Architecture, 2023). Among international colleges, Bartlett emphasises creative context (University College London, n.d.), MIT leads with innovation (Massachusetts Institute of Technology, n.d.), RMIT provides hands-on realism (Royal Melbourne Institute of Technology, n.d.), and NUS prioritises sustainable solutions grounded in systems thinking (National University of Singapore, n.d.). In contrast, Indian architecture schools show diverse strengths but face challenges in standardising frameworks for global benchmarking, integrating advanced technology, and balancing cultural identity with global innovation. The radar chart (Figure 2) visually represents the comparison between the curriculum frameworks of international and national architecture schools.

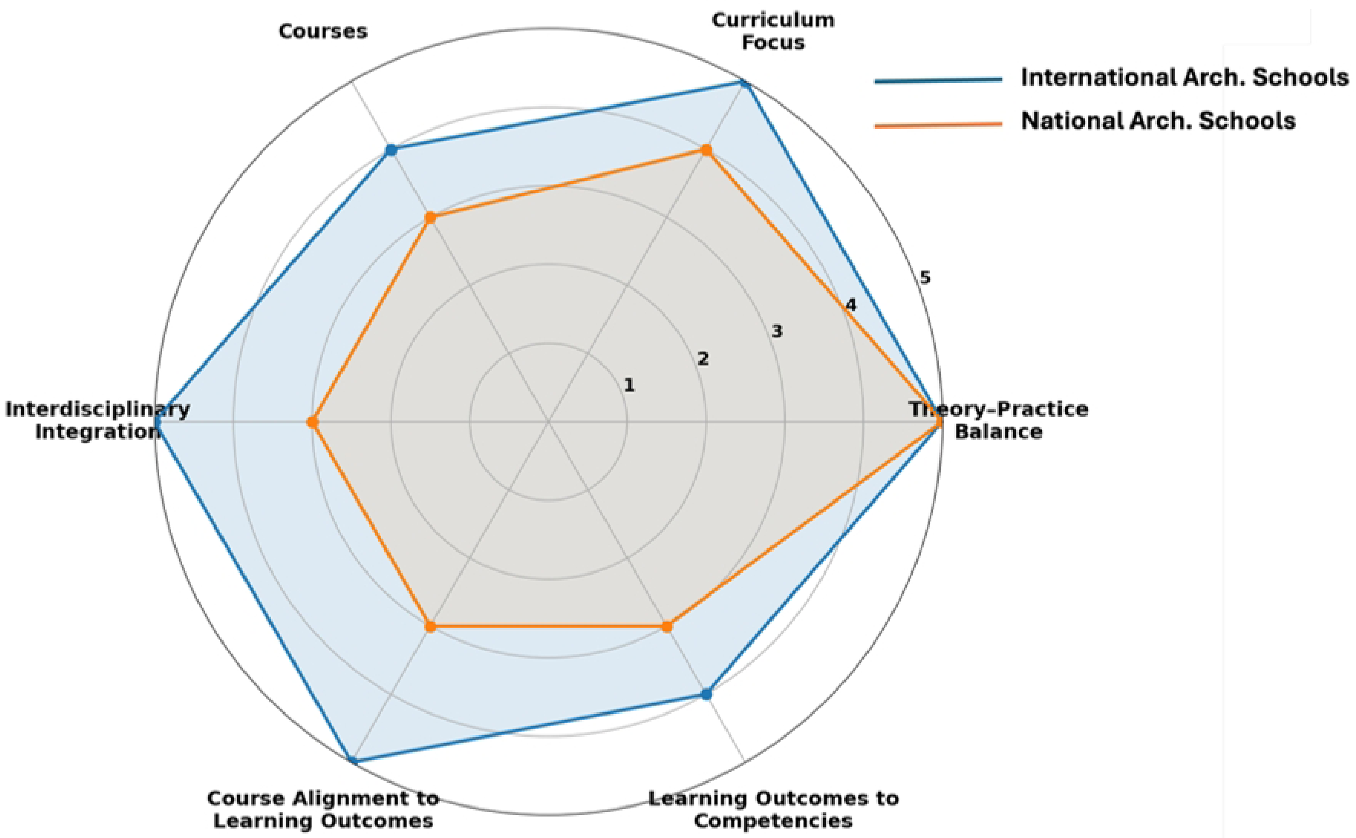

Figure 2: Comparison of curricula across Indian and international architecture schools

Comparative analysis of global regulatory bodies

The comparative analysis of regulatory bodies worldwide evaluated parameters such as theory–practice balance, curricular focus, core components, learning outcomes, competency mapping, interdisciplinary integration, and professional readiness. Official documents of global regulatory bodies were reviewed and summarised to identify key themes relevant to architectural education. These key themes were used to create word clouds highlighting the main themes, as shown in Figure 7 in the Appendix. Frequencies in the word clouds were then mapped onto a Likert scale, translating qualitative textual data into a semi-quantitative measure for easier comparison, as shown in Table 4.

Indian frameworks, represented by the AICTE and the COA, were compared with international frameworks such as the ARB, RIBA, NAAB, UIA, and AACA. Scores ranged from 1 to 5 (Shannon, 2012).

As shown in Table 4, international educational standards, such as those from the UK (RIBA), the USA (NAAB), and Australia (AACA), emphasise balanced integration between theory and practice. Studios form the core of the curriculum, often comprising 50%, and are supported by internships or practice-based assessments. National curriculum frameworks, including AICTE's six-month training and COA's reforms under NEP 2020, include internships and a thesis, but implementation is inconsistent. COA's multi-exit pathways offer greater flexibility but struggle to ensure consistent practical readiness (Council of Architecture, 2023). NAAB's Student Performance Criteria and AACA's Capability Profiles clearly demonstrate how global models focus on structured learning outcomes and lifelong professional development. These frameworks establish measurable competencies and provide a clear understanding of graduate expectations. India's COA proposes 30 Graduate Attributes, but it lacks a robust and rigorous system comparable to those of its international counterparts, which use tiered competency applications (Council of Architecture, 2023).

Cross-disciplinary learning, which integrates technology, sustainability, and management, is promoted as a crucial element in global curricula. India encourages such electives through AICTE and COA, although practical implementation varies (All India Council for Technical Education, 2019; Council of Architecture, 2023). Internationally, becoming a professional architect ties academic progress to practice-based examinations, such as ARB Part 3. In India, professional preparation includes internships and professional courses. The COA is currently discussing plans for a licensing examination; however, it does not yet have systems similar to ongoing competency checks, such as RIBA's CPD framework.

The comparative radar chart, shown in Figure 3, visually represents national and international architectural education standards and policies across seven core aspects.

	Balance between Theory & Practice	Curriculum Focus	Core Components / Program Structure	Learning Outcomes _ Competency mapping	Interdisciplinary Integration	Professional Readiness
ARB (UK)	3	3	2	4	4	5
	design-based learning integrated with technology; real-world focus.	Focus on aesthetics, ethics, environment, and building science.	11 Graduate Criteria aligned with EU directives.	Progressive skill development through Parts 1–3. Explicit K-U-S model evolving toward registration.	Encourages engineering and planning integration.	Rigorous licensure focus via ARB Part 3.
RIBA (UK)	5	4	2	3	4	5
	Studio, technical and ethics blended seamlessly.	Emphasizes climate, ethics, social equity and safety.	6 thematic benchmarks covering full career spectrum.	Structured for lifelong learning and CPD-readiness. Mapped to full career pathway and responsibilities.	Highly integrated with law, health, ethics, etc.	Professional readiness embedded in practice path.
NAAB (USA)	4	4	3	5	5	5
	Studio-based, real-world learning with community input.	Centred on equity, societal impact and research.	5 realms with clear Student Performance Criteria (SPC).	Outcome-driven, future-oriented, stakeholder focus. Detailed SPC matrix with ethical/design performance.	Aligns with climate science, management, computation.	Licensure and practice-focused from early stages.
UIA (Global)	4	4	4	3	5	5
	Balanced theory and practical inquiry + internships.	Covers global-local, culture, human needs, tech.	Modules across visual, tech, theory, and practice.	Focus on professional versatility and ethics. Global competencies in culture, design, and society.	Transdisciplinary and multicultural approach.	Global reciprocity and validation for practice.
AACA (Australia)	4	3	3	3	4	5
	Staged education with applied knowledge & assessment.	Indigenous, ecological, lifecycle-focused thinking.	Performance Criteria with Capability Profiles.	Tiered outcomes via reflection and technical growth. Cultural, sustainability, and local context framed.	Integration of sociology, tech, Indigenous systems.	Practice-based learning aligned with licensure.
AICTE (India)	4	3	3	3	5	4
	Internships, workshops, studios aligned to practice.	Heritage, employability, entrepreneurship-focused.	Structured as Core + Specialization with internship.	9 learning outcomes focusing on teamwork, ethics. Mapped into 4 competency domains.	Choice-based interdisciplinarity	Internships and ethics embedded in final semester.
COA (India)	3	3	3	3	3	5
	practice-integrated with studio & internship.	Aligned with NEP 2020: flexibility, interdisciplinarity.	Graduate Attributes grouped under design, ethics, etc.	Supports lifelong learning and global professionalism Competencies cover design, ethics, urbanism, etc.	Cross-disciplinary pathways via flexible systems.	Licensure support, modular registration approach.

Table 4: Comparative analysis of educational standards set by regulatory bodies worldwide

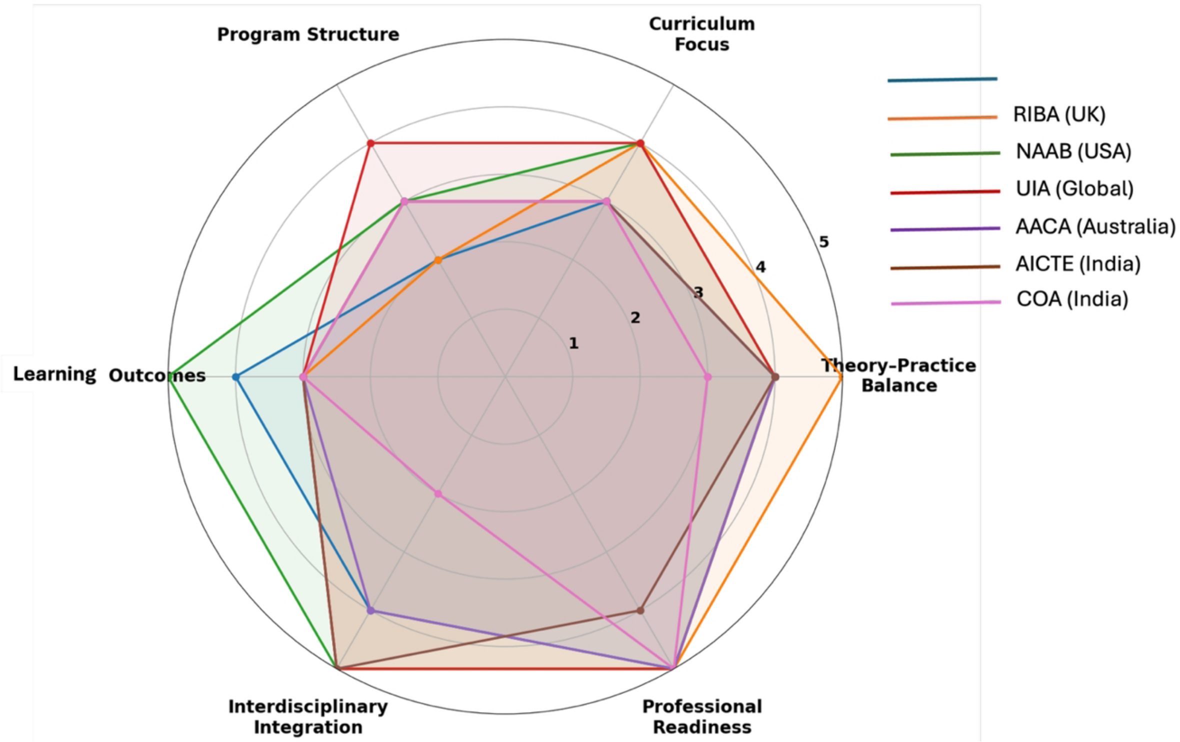

Figure 3: Comparison of Indian and global regulatory bodies

Alignment between competencies set by COA and academia

As discussed previously, the Council of Architecture (COA), as the dominant regulatory body for architectural education and practice in India, has compiled essential knowledge (K), skills (S), and attributes (A) for architecture graduates through extensive consultations, including:

a) stakeholder consultations, in which COA engaged various stakeholders in architecture education, including academic institutions and industry leaders, to gather diverse perspectives on necessary professional competencies;
b) analysis of existing practices, including reviews of current national and global educational practices and standards;
c) research and benchmarking against allied professions to help establish relevant competencies aligned with evolving architectural demands;
d) alignment with national policies such as NEP; and
e) workshops and symposia with educators and industry practitioners to validate the proposed competencies and ensure their relevance to the current and future contexts of architecture education.

In its latest circular released in January 2023 (Council of Architecture, 2023), the Council of Architecture (COA) identified several key KSA domains for graduates of accredited architecture programmes, as shown in Table 5.

Architectural education covers key areas, including architectural design, which encompasses aesthetic and functional space creation, and building relationships, which focuses on connections among people, structures, and the environment. Formal ordering systems explore visual perception and design principles in both two- and three-dimensional design. Cultural contexts and global practices examine local, regional, and national traditions, fine arts, diverse histories, and heritage responsibilities, while building science concepts emphasise technologies that ensure climate comfort and safety. Vocational skills in architecture comprise arts, graphics, digital tools, site analysis, construction materials, and urbanism. Professional skills focus on integrating site planning, structures, services, and cultural and climatic contexts. Critical thinking fosters and nurtures analytical abilities essential for discourse, while ethical sensibilities highlight the architect's societal responsibilities.

Attributes such as social responsibility, understanding human behaviour in relation to the physical environment, and self-awareness promote effective leadership through emotional and ecological intelligence. Lifelong learning ensures adaptability and continuous education in the evolving field.

These competencies, defined by COA in alignment with NEP 2020, help ensure that graduates are prepared with the knowledge, skills, and attributes needed to address architectural challenges.

Table 6 summarises the KSAs defined by institutions such as SPA Delhi, NIT Calicut, KRVIA, IIT Roorkee, and NIRMA University. Architecture programmes across Indian institutions blend foundational knowledge, technical expertise, and professional skills. SPA Delhi gives primary focus to sustainability and architectural principles while encouraging innovative thinking. NIT Calicut focuses on sustainable design, interdisciplinary collaboration, and ethical responsibility, while KRVIA emphasises and fosters creativity and adaptability to global changes. IIT Roorkee aims to bring together engineering, sustainability, and digital proficiency to address real-world challenges. Nirma University blends theoretical frameworks with digital tools and global exposure, promoting adaptability and research capabilities.

A cross-analysis of the knowledge, skills, and attributes (KSAs) identified by COA with the curricula of five national architecture schools was conducted using a 1–5 Likert scale to measure and gauge alignment (Pang et al., 2019). Figure 4 illustrates

	Knowledge	Skills	Attributes
COA	**Architectural Design**: Understanding aesthetic and functional requirements in architectural design to create liveable habitats.	**Vocational Skills**: Including arts and graphics, digital competency, site analysis, construction materials, and understanding of urbanism and landscape.	**Social Responsibility**: Recognition of architects' roles in addressing social factors within their professional practice.
	Building Relationships: Knowledge of the interrelationships between people, buildings, and the environment.	**Professional Skills**: Ability to integrate site, space planning, structure, and services while considering larger cultural and climatic contexts.	**Human Behaviour**: Knowledge of how human behaviour interacts with the physical environment, considering diverse needs and values.
	Formal Ordering Systems: Grasping the fundamentals of visual perception and principles of order in two- and three-dimensional design.	**Critical/Responsive Thinking**: Developing analytical and reflective skills crucial for architectural discourse and practice.	**Self-Awareness and Leadership**: Promoting self-awareness and understanding various intelligences (emotional, ecological, etc.) crucial for effective leadership in architecture.
	Cultural Contexts: Awareness of local and regional traditions and practices, as well as the influence of fine arts on architectural design.	**Ethical Sensibilities**: Understanding the ethical responsibilities of the architect in practice and society	**Commitment to Lifelong Learning**: Preparing graduates to pursue continuous education and adaptation in an evolving professional landscape.
	Global Practices: Knowledge of divergent architectural histories and practices across the world, along with cultural heritage responsibilities.		
	Building Science Concepts: Understanding physical building problems and technologies ensuring comfort and protection from the climate.		

Table 5: KSAs defined by the Council of Architecture (COA) for a fresh graduate

College	Knowledge	Skills	Attributes
SPA Delhi	3	3	3
	- Foundational education in architecture	- Application of design principles	- Innovative thinking
	- Core subjects covering essential aspects of architecture	- Critical analysis and problem-solving	- Responsibility towards the environment
	- Understanding of sustainability and environmental impact	- Professional communication - Technical proficiency in design tools	- Leadership capabilities
NIT Calicut	2	2	2
	- Design principles and sustainable architecture	- Design development and conceptual skills	- Ethical responsibility
	- Knowledge of interdisciplinary collaboration and research methodologies	- Analytical and research skills	- Commitment to societal impacts of design
	- Technical knowledge including structural systems and building technology	- Project management and teamwork	
KRVIA	3	3	2
	- Knowledge in various design domains (knowledge, practice, critical, regional)	- Proficiency in design thinking	- Critical awareness of architecture's social context
	- Appreciation of the cultural and historical contexts of architecture	- Creative competencies in design	- Adaptability to globalization and technology impacts
IIT Roorkee	4	4	3
	- Technical knowledge covering engineering principles, building technology	- Problem analysis and critical thinking	- Professional readiness and ethical standards
	- Sustainability and environmental awareness	- Research and investigation skills - Digital proficiency	- Educational preparedness for real-world challenges
Nirma University	3	2	2
	- Integrated design processes and theoretical frameworks	- Digital representation skills	- Flexibility and adaptability in learning
	- Research methodology and proposal development	- General architectural practice skills	- International awareness and exposure

Table 6: Alignment of KSAs established by COA with premier national universities

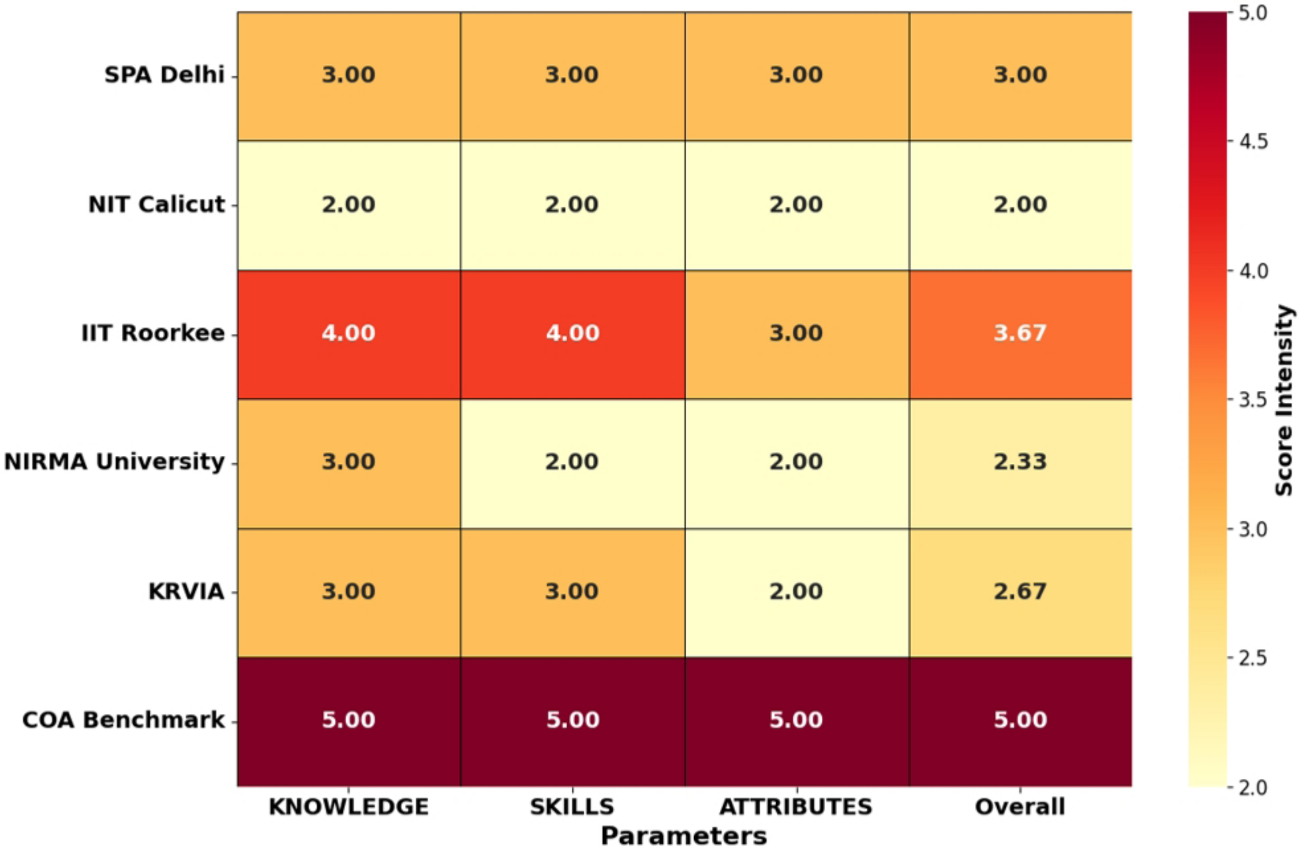

Figure 4: Heat map of the alignment between COA competencies and academic competencies

this alignment and highlights key areas for competency and curriculum enhancement to better align with global standards (Modabber Dabagh, 2019). The significance and implications of these findings are explored in the following discussion.

DISCUSSION

This study aimed to evaluate and compare ADE curricula across premier architecture schools in India and internationally. It sought to identify commonalities and differences in the curricula and competencies offered by these institutions. In addition, it examined discrepancies among regulatory bodies in India and internationally, as well as the alignment between the competencies set by COA and those of architecture schools in India. By highlighting discrepancies, the study aims to inform architecture schools and regulatory bodies as they reconsider their approaches. Ultimately, it aims to develop a competency assessment framework that encourages alignment and improvement of curriculum standards in India.

As shown in Table 3 and Figure 2, the architecture schools clearly highlight the following pattern. International architecture schools are widely recognised for their flexibility, global integration, and interdisciplinary curricula, as also highlighted by Dupre (2021) and Maneshi et al. (2023). In contrast, Indian architecture schools provide strong technical preparation and are attempting to advance rapidly in areas such as artificial intelligence, sustainability, and a wider range of electives. Chandavarkar (2018), Jerome and Maulik (2024), and Naralasetty and Ugrani (2023) support this finding in their studies. Regarding core, major, and minor courses, both types of institutions equip students effectively with foundational and advanced design concepts. However, the most noticeable discrepancy and challenge lies in integrating interdisciplinary and innovation-focused learning, followed by differences in curricular emphasis (Pandit, 2019; Hammadamin and Nordin, 2024). Overall, while both systems have strengths, integrating emerging technological developments and more collaborative learning methods could enrich and strengthen the traditional frameworks of architectural design education, particularly in Indian schools.

As shown in Table 4 and Figure 3, the comparison of regulatory bodies in India and internationally provides the following insights. NAAB (USA) and UIA (Global) emerge as global leaders, scoring the highest across all metrics. Bhattacharjee and Bose (2015) highlight how these two bodies maintain robustly blended academic practices that contribute to their global leadership status. AACA (Australia) and ARB (UK) are well balanced, especially in relation to sustainability and indigenous or local relevance. Dupre (2021) supports this finding and discusses Australia's innovative inclusion of local contexts and sustainability in architectural education, supporting AACA's focus. AICTE (India) focuses primarily on employability and applied knowledge but could benefit from more globally aligned competency and outcome structures. Bongirwar and Das (2022) and Shannon (2012) both discuss India's emphasis on job readiness through practical training. However, gaps remain in outcome-based education (OBE) and global competency benchmarking. COA (India) shows strong

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alignment with NEP 2020 reforms and particularly aims to strengthen interdisciplinarity and professional readiness. However, it underperforms in balancing theory and practice, establishing a strong curricular focus, and ensuring consistent learning outcomes. Naralasetty and Ugrani (2023) and Jerome and Maulik (2024) show that COA has embraced the NEP 2020 vision by promoting professional relevance and interdisciplinarity. Nevertheless, challenges persist in curriculum coherence, particularly when aligning theory with practice.

In summary, NAAB and UIA are global frontrunners in architectural education, while other bodies, such as AACA, ARB, AICTE, and COA, demonstrate multiple strengths and challenges in domains such as sustainability, employability, and curriculum coherence. These findings highlight areas where reform and revision are needed.

As illustrated in Figure 4, the alignment between the KSAs set by COA and those established by premier architecture schools in India varies. Keeping COA as the benchmark, IIT Roorkee exhibits the highest alignment (score = 3.67) with COA-prescribed competencies, scoring highly in the knowledge and skill domains and moderately in the attribute domain. IIT Roorkee aims to bring together engineering, sustainability, and digital proficiency to address real-world challenges. SPA Delhi displays moderate alignment with the KSAs prescribed by COA, with an overall score of 3. SPA Delhi gives primary focus to architectural principles and sustainability while encouraging innovative thinking. KRVIA aligns moderately well in the knowledge and skill domains but falls short in attributes. KRVIA emphasises and fosters creativity and adaptability to global changes. NIT Calicut and NIRMA University both have below-average scores, displaying low alignment with the COA-prescribed competencies.

The findings from the parameter comparison between national regulatory bodies sharply contrast with those from the curriculum framework analysis of the five national architecture schools in the interdisciplinary integration domain. A similar contrast is observed in the curriculum focus domain, revealing gaps in the broader framework. Moreover, AICTE takes a more traditional or orthodox approach and needs to re-evaluate and reconsider its strategies, which is corroborated by Bongirwar and Das (2022). In contrast, COA aims to align more closely with global regulatory bodies (Naralasetty and Ugrani, 2023; Chandavarkar, 2018). Yet, architecture schools in India, including premier institutions, show discrepancies and hesitation in adopting the KSAs set by COA, which is again supported by Pandit (2019). This study is limited by its specific educational context: the selected architecture schools in India and globally, as well as the accrediting bodies considered. This may affect broader generalisability.

Competency-based assessment framework and its implications

Given the identified gaps in ADE in India and the best practices followed by NAAB and RIBA, a competency assessment framework is proposed. The framework was designed based on curriculum, standards, policy analysis, and the alignment of curricula with COA-prescribed competencies.

The proposed competency assessment framework supports the standardisation of competency evaluation across stakeholders. This can help architecture schools in India become more efficient and responsible in delivering quality architectural education. Reducing ambiguous assessment criteria can streamline academic evaluation processes, improve the comparability of student performance, and facilitate quicker interpretation of competencies by recruiters. Beyond operational efficiency, the framework also aims to support responsible educational practice. Transparent competency indicators can promote fairness and accountability in assessment while reducing risks associated with subjective evaluation. Finally, the competency assessment framework is envisioned as a practical, measurable, and adaptable tool to help all three stakeholders:

a) students recognise their strengths and address their shortcomings;
b) recruiters select talent based on framework analysis; and
c) faculty customise the framework based on curriculum and student performance at each architecture school, considering curricular focus or contextual differences. In addition, it will enable longitudinal tracking of students' overall academic performance.

The initial step involved cross-analysing and categorising all KSAs into a framework composed of six distinct domains, as illustrated in Table 7.

The assessment framework was renamed the PREDICT assessment framework, derived from the initials of its constituent domains. Subsequently, the courses prescribed by COA were systematically aligned in Table 8 with the six identified competency domains using a statistical programming tool to provide a clearer understanding of the evaluation rubric (Kabir et al., 2024).

Competency Domain	What it covers	K/S/A
Professionalism & Lifelong Learning	Project management, regulation compliance, entrepreneurship, CPD-readiness.	S, A
Research & Critical Analysis	Problem-solving, contextual analysis, evidence-based design, future-readiness.	K, S
Ethics & Social Responsibility	Professional integrity, public safety, sustainability, cultural awareness.	S, A
Design Thinking & Innovation	Conceptual ability, creativity, user-centric design, iterative refinement.	S, A
Communication & Collaboration	Visual, verbal, and written communication; teamwork; Interpersonal engagement.	K, S
Technical Proficiency	Building systems, environmental design, digital tools, structural understanding.	K, A

Table 7: Competency domains identified from COA-prescribed KSAs (where K is Knowledge, S is Skills, and A is Attributes)

Course/Subject	Mapped Domain	K/S/A
Architectural Design Studios (I to Thesis)	Design Thinking & Innovation	S, A
Architectural Design Studios (I to Thesis)	Communication & Collaboration	S, A
Architectural Design Studios (I to Thesis)	Technical Proficiency	K, S
Building Construction & Materials	Technical Proficiency	K, S
Building Services	Technical Proficiency	K, S
Structural Systems & Design	Technical Proficiency	K, S
Environmental Studies / Climatology / Sustainability	Ethics & Social Responsibility	K, A
Environmental Studies / Climatology / Sustainability	Technical Proficiency	K, S
History, Theory & Humanities	Research & Critical Analysis	K, S
History, Theory & Humanities	Ethics & Social Responsibility	K, A
Working Drawing, Cost Estimation & Project Management	Professionalism & Lifelong Learning	K, A
Working Drawing, Cost Estimation & Project Management	Technical Proficiency	K, S
Urban Design & Landscape Design	Design Thinking & Innovation	S, A
Urban Design & Landscape Design	Research & Critical Analysis	K, S
Professional Practice / Legal Responsibilities	Professionalism & Lifelong Learning	K, A
Professional Practice / Legal Responsibilities	Ethics & Social Responsibility	K, A
Internship / Training	Professionalism & Lifelong Learning	K, A
Soft Skills / Communication / Life Skills	Communication & Collaboration	S, A
Soft Skills / Communication / Life Skills	Professionalism & Lifelong Learning	K, A
Research Writing / Thesis Report / Dissertation	Research & Critical Analysis	K, S
Research Writing / Thesis Report / Dissertation	Design Thinking & Innovation	S, A

Table 8: Association mapping of COA-defined courses to the six competency domains (where K is Knowledge, S is Skills, and A is Attributes)

To evaluate individual competencies in ADE, a four-level rubric is proposed, modified, and adapted from Lutnæs (2018), Pop-Iliev and Platanitis (2008), and Allen and Tanner (2006). The rubric assesses student performance based on defined knowledge, skills, and attributes. The terminology has been rephrased to present a more positive, encouraging, and constructive tone in order to enhance students' and potential recruiters' motivation.

Level 1 – Emerging (0-25%)	*Level 2 – Developing (26-50%)*	*Level 3 – Proficient (51-75%)*	*Level 4 – Advanced (76-100%)*
The learner has a limited understanding of the competency, needing continuous guidance to apply concepts.	The student shows a basic level of skill related to the competency, performing tasks with some success, but lacks consistency.	The learner applies the competency effectively and independently, showing confidence and a solid grasp of related concepts.	The learner integrates the competency across contexts, innovates, or leads others in its use, reflecting high autonomy, creativity, and leadership competency.

Table 9: Competency Evaluation Rubric

Validation of the competency-based assessment framework

To study the adoption and execution of the proposed PREDICT framework, six student work samples from below-average, average, and above-average categories were considered. The studio course from Year 4 was selected to validate the competency-based assessment framework because the course addresses all competency domains. The importance assigned to each competency domain varies, as shown in Table 10, according to the faculty member leading the course.

C1	**Professionalism & Lifelong Learning** (Project management + CPD-readiness)	10%
C2	**Research & Critical Analysis** (Problem-solving +contextual analysis)	20%
C3	**Ethics & Social Responsibility** (Professional integrity + sustainability)	10%
C4	**Design Thinking & Innovation** (Conceptual ability + creativity + user-centric design)	30 %
C5	**Communication & Collaboration** (teamwork + interpersonal effectiveness)	10%
C6	**Technical Proficiency** (Building systems + digital tools competence)	20%

Table 10: Distribution of competency weightage for the studio course

After evaluating the six student projects, a visual competency profile was created for each, as shown in Figure 5. In the competency profile visualisation, the scoring scale is divided into four performance levels aligned with the competency rubric: 0–25 (Emerging), 26–50 (Developing), 51–75 (Proficient), and 76–100 (Advanced). In the current study, only one course was selected to demonstrate the application of the competency framework. However, the framework needs to be applied to each course across semesters and across all years so that a cumulative competency profile can be developed for each student.

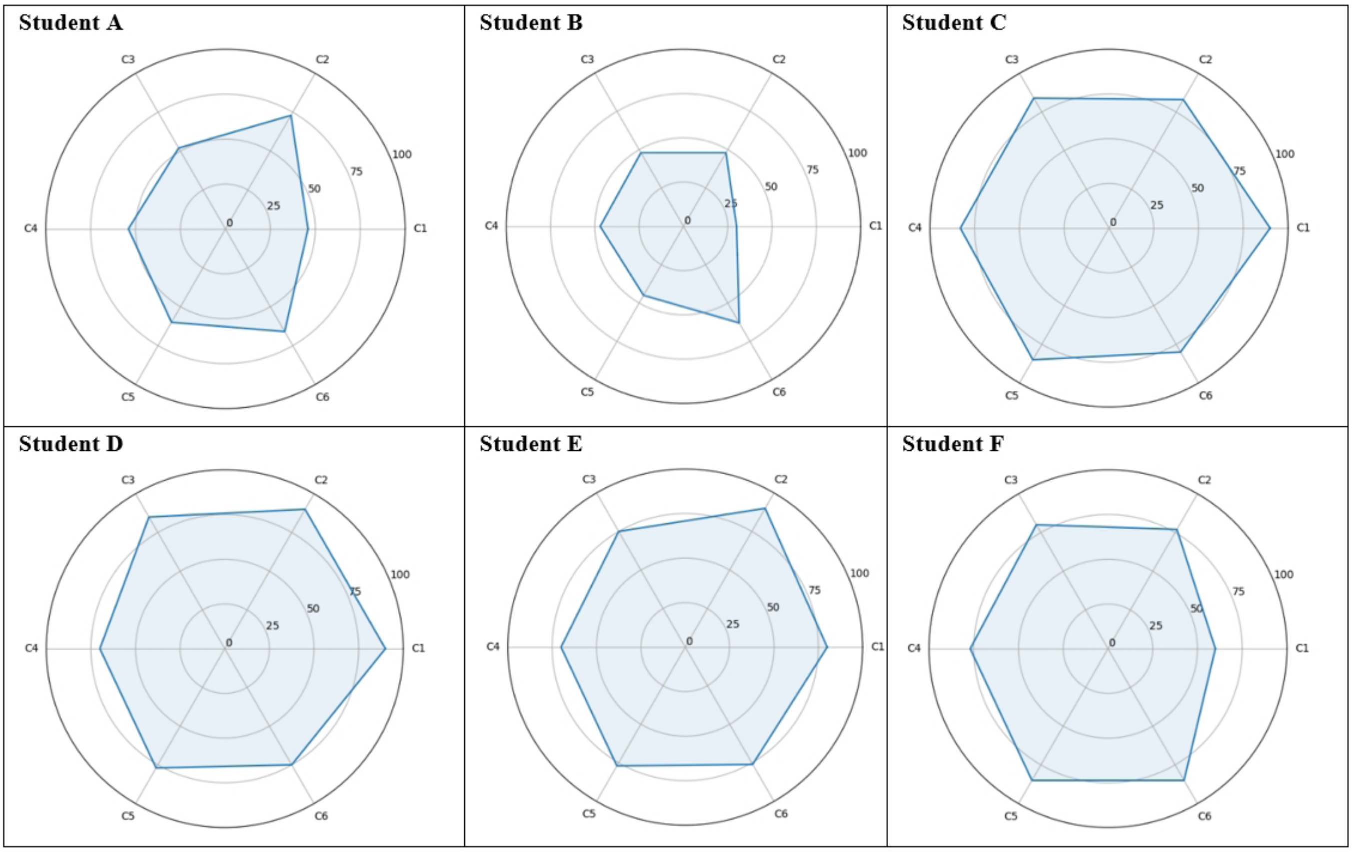

Figure 5: Distribution of competency weightage for the studio course

An overall analysis of the radar chart data across the six competency domains shows a generally strong performance profile, with a few clear areas for improvement. When the performance of all students is averaged, C2—Research and Critical Analysis and C3—Ethical and Social Responsibility emerge as the strongest domains, each with an average of about 82%. C5—Communication and Collaboration also appears as a stable strength, with an average of around 80% and no student scoring below 60%, making it another reliable area of performance across the cohort. C6—Technical Proficiency shows reasonably good performance, with an average of approximately 78%. However, there is some variation in scores, indicating that foundational understanding remains unclear and is still developing for some students. The first major area of concern is C4—Design Thinking and Innovation, which has a lower average of about 73.5% and a wide score spread ranging from 56% to 87%. C1—Professionalism and Lifelong Learning is also a major area of concern, with substantial variation in student scores.

Visual representations of competency profiles can help all three stakeholder groups in several ways: academics can study curriculum effectiveness, students can become more self-aware of their strengths and work on areas for growth, and practitioners can benefit from job-ready profiles. Analysis of competency profiles after every semester and year can reveal repeated weak competency areas, curriculum gaps, skill gaps in the graduating cohort, and alignment with industry expectations. The pilot testing of the framework demonstrates its potential to improve efficiency and support responsible assessment practices.

CONCLUSION

This study reviewed the current state of ADE in India and internationally to reveal noticeable gaps in academia. Architecture schools worldwide prioritise interdisciplinary learning, innovation, and global perspectives. They combine theory and practice, emphasising sustainability, cultural depth, regional relevance, professional readiness, and societal impact while integrating internships and vernacular design to align education with global challenges. Global bodies such as ARB, RIBA, NAAB, and UIA emphasise design depth, ethics, and interdisciplinary exposure. Meanwhile, Indian institutions such as AICTE and, more prominently, COA prioritise regional relevance, employability, and flexibility in line with NEP 2020. All frameworks foster competency-based learning by blending technical skills with cultural awareness. However, Indian architecture colleges face challenges in aligning with COA standards because of limited flexibility, inadequate technology integration, and inconsistent operational practices compared with global institutions.

In response to these insights, this study proposes the competency-based PREDICT assessment framework as a strategic tool for bridging the identified gaps. The framework defines a structured set of six competencies. The gaps identified in ADE can be addressed through the six competency domains of the PREDICT framework. Weak industry readiness and limited exposure to practice are mitigated through Professionalism and Lifelong Learning (C1), which strengthens project management, regulatory awareness, and continuous professional development. The shortcomings in critical thinking and research orientation are addressed by Research and Critical Analysis (C2), which fosters evidence-based design and contextual problem-solving. Gaps related to ethics, sustainability, and social responsibility are aligned with Ethics and Social Responsibility (C3), embedding environmental and cultural awareness in design processes. Constraints on creativity caused by rigid curricula are countered by Design Thinking and Innovation (C4), which promotes user-centred, iterative, and exploratory approaches. Similarly, deficiencies in communication and teamwork are addressed through Communication and Collaboration (C5), enhancing interdisciplinary engagement and presentation skills. Finally, technical skill gaps are bridged by Technical Proficiency (C6), which strengthens competence in building systems and digital tools and thereby narrows the gap between academia and practice.

The PREDICT framework supports the study's aims by balancing theory and practice and by requiring regular curriculum review to match the competency framework. Once adopted by all colleges, it can promote consistency and accountability in curriculum content and assessment. By standardising competency criteria for students, educators, and recruiters, it can foster efficient assessment and decision-making. Overall, it enhances responsible architectural education and aligns theoretical knowledge with practical training. Future work will involve testing this assessment framework on a larger scale across all stakeholders, collecting feedback from educators, practitioners, and students, and refining the tool for broader implementation in architecture schools.

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APPENDIX

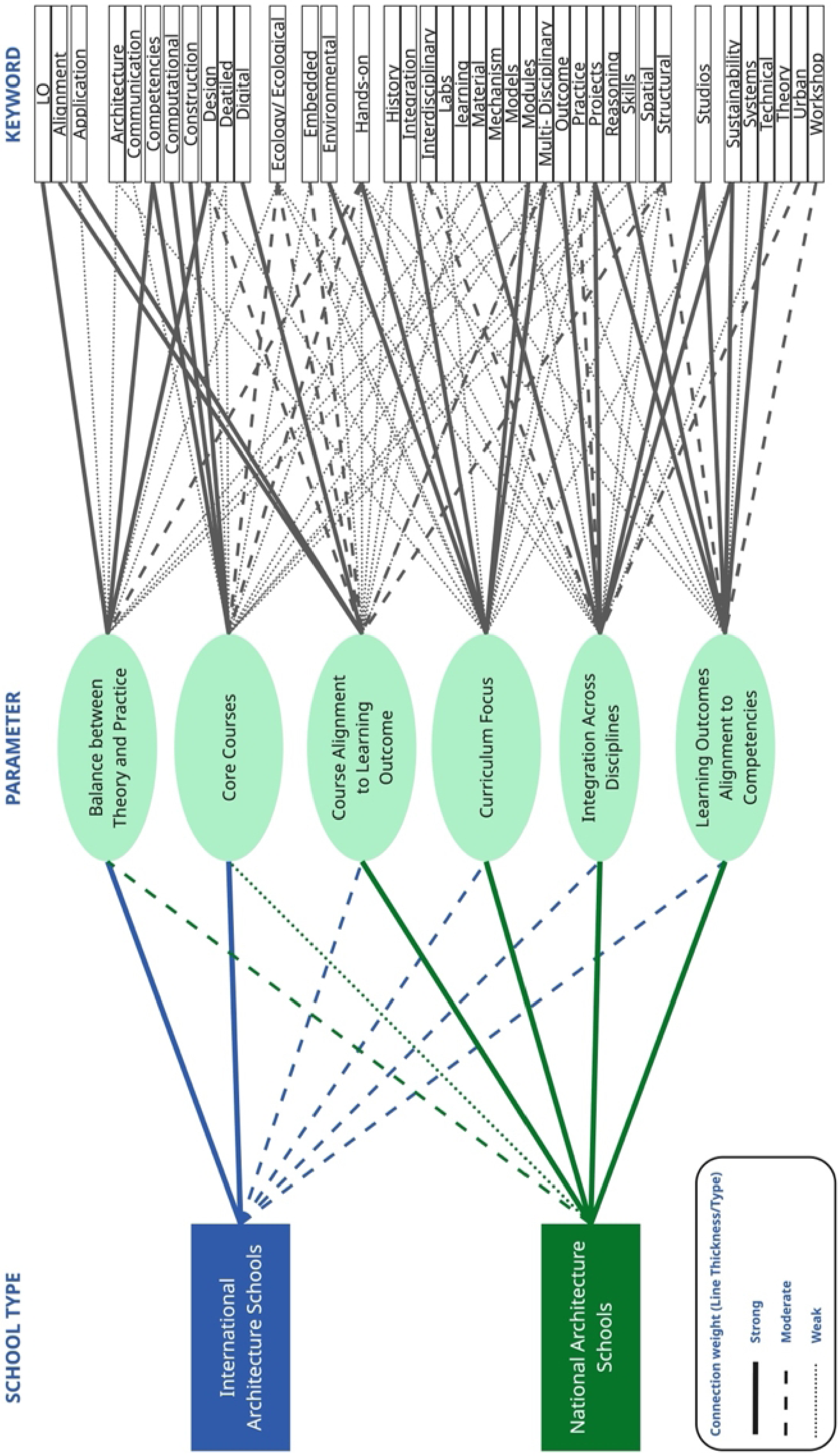

Figure 6: Network diagram showing analysis of global and Indian architecture schools

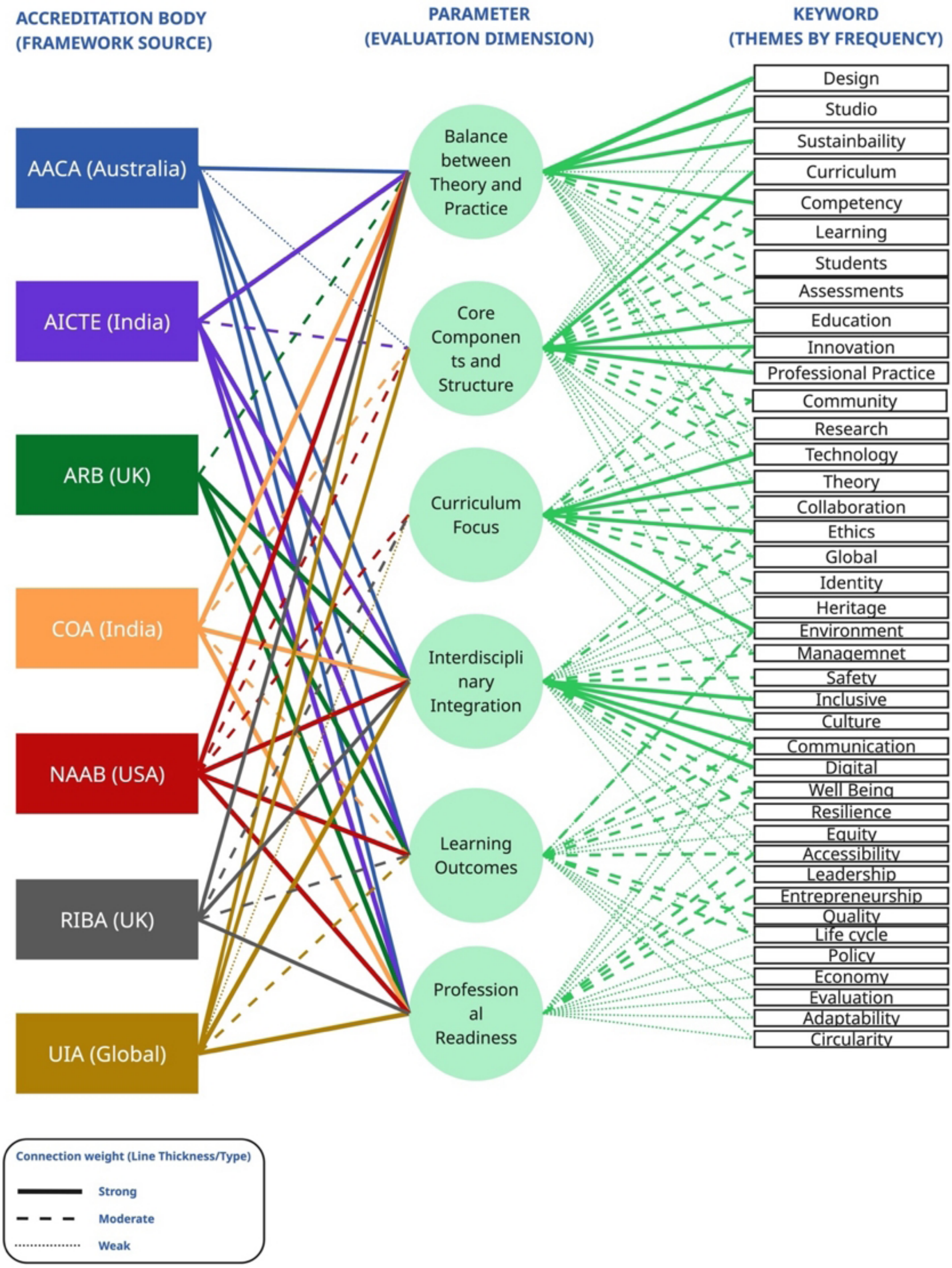

Figure 7: Network diagram showing analysis of global architecture regulatory bodies

A DIMENSIONAL ANALYSIS OF JUNIOR HIGH SCHOOL STUDENTS' CRITICAL THINKING SKILLS

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ABSTRACT

Critical thinking skills (CTS) are essential competencies for 21st-century students; however, empirical evidence indicates that their development remains suboptimal. This study aimed to map the CTS profile of junior high school students in Bali Province, Indonesia, and to examine differences across CTS dimensions. A survey design was used, involving 403 students selected through multistage random sampling from public and private schools across eight regencies and one city in Bali Province, Indonesia. Data were collected using a content-free CTS test developed by the authors, which demonstrated content validity and high reliability (Cronbach's α = 0.920). The data were analysed using descriptive statistics and repeated-measures analysis of variance after assumption testing. The results showed that students' overall CTS remained low, with average mastery below 60%. Significant differences were found across dimensions: evaluation and interpretation had the highest scores, whereas analysis and explanation had the lowest. These findings provide a provincial-level empirical basis for developing more targeted strategies, assessments, and educational policies to strengthen CTS.

KEYWORDS

Bali Province, critical thinking skills, educational assessment, junior high school students, responsibility in education

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Highlights

- *CTS among junior high school students in Bali were generally low.*
- *Evaluation and interpretation scores exceeded those for analysis and explanation..*

INTRODUCTION

In the 21st century, critical thinking skills (CTS) have become an essential foundation in education, as life is increasingly complex and rapidly changing (Kim and Jeon, 2019; Mahanal et al., 2019). CTS help individuals analyse information in depth (Mutakinati et al., 2018; Hacioglu and Gulhan, 2021), identify weaknesses in arguments objectively and avoid being easily misled (Changwong et al., 2018; Sasson et al., 2018; Alsaleh, 2020), and make rational decisions in complex work and personal situations (Seibert, 2021). Amid technological advances and the information explosion, CTS enable individuals to sort through diverse data sources more carefully (Gurcay and Ferah, 2018), consider different perspectives when forming fair judgements (Ulger, 2018), and develop innovative solutions to problems that do not always have a single answer (Ulger, 2018; Wechsler et al., 2018). In other words, CTS are not only about "right or wrong" answers, but also about the quality of reasoning, learning resilience, and adaptability in a rapidly changing environment.

Conversely, individuals who lack CTS are vulnerable to information manipulation through deception, indoctrination, brainwashing, hate speech, and fake news (Marin and Copeland, 2022). This vulnerability arises when information is received without adequate analysis and verification. Misleading opinions can easily influence individuals, especially when framed in emotional and persuasive ways. Ultimately, decisions may be made on the basis of emotion rather than logic and evidence, potentially harming both individuals and others. Furthermore, without CTS, individuals also tend to have difficulty addressing complex problems that require in-depth analysis and reflection in both academic and social settings.

This situation becomes even more concerning in the context of basic education, particularly junior high school, which is a crucial phase in shaping students' thinking. At this level, students are required not only to understand subject matter but also to reason, analyse, and solve problems presented across various subjects. At the same time, junior high school students are among the age groups vulnerable to the negative influence of the vast flow of information on social media (Höttecke and Allchin, 2020; Shu et al., 2020; Wong et al., 2021). Without CTS, they risk becoming victims of digital fraud and information manipulation and may become involved in spreading hoaxes that can harm themselves and their environment (Zubair et al., 2019). Therefore, strengthening CTS among junior high school students is an urgent need in the current context of education and digital literacy.

Various studies have evaluated students' CTS at different educational levels, and their findings are consistent: students' CTS remain relatively low. This phenomenon is a global concern because it directly affects young people's readiness to face the challenges of the 21st century. Low CTS have been reported in several countries, including Nigeria (Chinaka et al., 2018), the United States (Reynders et al., 2020), Vietnam (An-Le and Hockey, 2021), the Netherlands (Ritter and Mostert, 2017), and the United Kingdom (Nejmaoui, 2018). A similar situation has also been found in Indonesia. Various studies have shown that students' CTS have not reached the expected level (Fuad et al., 2017; Mutakinati et al., 2018; Basri et al., 2019; Pratama et al., 2019; Saputri et al., 2019; Amin et al., 2020; Sumarni and Kadarwati, 2020; Saenab et al., 2021). The consistency of these findings demonstrates that low CTS are not merely a local issue but a systemic challenge that must be understood through robust and representative profile mapping.

Although many studies report low CTS, research that maps the CTS profile of Indonesian students in greater depth still has limitations, particularly in terms of location coverage, the number of participants, and the quality of the instruments used. Himmatussolihah et al. (2020) studied students' CTS in Surakarta, Indonesia, but included only three 10th-grade high school students, making the findings difficult to generalise. Furthermore, the test used (Cornell Critical Thinking Test/CCTT Level X) did not explain its validity and reliability. Kamsinah et al. (2020) analysed junior high school students' CTS in South Kalimantan, Indonesia, but the sample size was not specified. The instrument, an essay-based approach, covered only temperature and heat, making its scope narrow. Azmi et al. (2022) studied junior high school students' CTS in Palembang, Indonesia, but only in one school, limiting generalisability. The test development indicators were based on Ennis, but the test's validity and reliability were not reported. Saphira and Prahani (2022) described the CTS profile of high school students in Surakarta, Indonesia, but their sample was limited to 10th-grade science students, making it less representative. The test was developed for parabolic motion, and its validity and reliability were also not reported. Fitriani et al. (2022) examined CTS among high school students in Bengkulu, Indonesia, but the study was also limited to a single school. Although they used Ennis indicators, the instrument's validity and reliability were not reported. In general, these studies show a similar pattern of limitations: the number of schools and participants was small, and the instruments did not meet measurement-quality reporting standards, thereby reducing the accuracy of CTS mapping for the broader population. Most instruments were also content-bound and limited to specific subject matter, reducing their suitability for broader profiling of students' CTS.

Given these limitations, no research has yet mapped the CTS profile of junior high school students in Bali Province, Indonesia, using a standardised, content-free CTS test. Therefore, the novelty of this study lies in its province-wide coverage of Bali Province and its stratified random sample from all regencies/cities. Unlike previous research, which has generally been limited to a single school or city, this study seeks to provide a comprehensive picture of junior high school students' CTS at the provincial level, thereby offering a stronger basis for planning development, improving learning, and strengthening critical literacy in schools.

The instrument used in this study was developed in the authors' previous work and has demonstrated content validity and high reliability (α = 0.920) (Redhana and Sudiana, 2015), thus ensuring stronger measurement quality. Furthermore, this study analysed CTS across five main dimensions (evaluation, interpretation, analysis, inference, and explanation) and employed robust statistical approaches, including repeated-measures ANOVA and pairwise comparison tests, to accurately identify differences among CTS dimensions. The use of a proportional conversion-based score classification system also facilitates interpretation on a 0–1 scale.

Beyond its cognitive importance, the present study is also relevant to issues of efficiency and responsibility in education and science. From the perspective of educational efficiency, mapping students' CTS across dimensions provides an evidence-based basis for designing more targeted instructional interventions, assessment practices, and teacher support. Without such a profile, schools and policymakers may implement broad and resource-intensive programmes that are less effective because they do not address students' actual areas of weakness. From the perspective of responsibility, CTS are essential for preparing students to evaluate information carefully, justify claims with evidence, and respond to social and scientific issues in a rational and ethically responsible manner. In this sense, identifying students' CTS profile is not only a measurement task but also a step towards more efficient educational decision-making and more responsible educational practice.

Therefore, this study contributes not only to the assessment literature on CTS but also to the broader agenda of improving efficiency and responsibility in education by providing a provincial-level evidence base for targeted and accountable pedagogical action. Accordingly, this study addressed two research questions: (a) What is the CTS profile of junior high school students in Bali Province, Indonesia? and (b) Are there differences in students' CTS across dimensions?

The remainder of this manuscript is organised as follows. The next section reviews the relevant literature on CTS and their dimensions. The subsequent section explains the materials and methods of the study, followed by the results, discussion, and conclusion.

LITERATURE REVIEW

CTS have been conceptualised in various ways in the educational literature. This section reviews the relevant literature and theoretical perspectives that inform the present study. A deeper understanding suggests that CTS are not simply a collection of discrete cognitive skills but rather a form of disciplinary and reflective knowledge. Ontologically, CTS are often understood as a set of observable abilities, such as evaluating, interpreting, and analysing (Song and Cai, 2024; Rahmasari and Susilo, 2025). However, epistemologically, CTS concern how individuals construct, justify, and validate knowledge in specific contexts (Dai, 2025). This epistemological perspective positions CTS as a reasoning practice rooted in evidence-based justification rather than merely surface cognitive performance (Pfister, 2025).

Drawing on Ennis's operationalisation and Facione's taxonomy of skills, this study positions the five dimensions of CTS—evaluation, interpretation, analysis, inference, and explanation—as interrelated epistemic practices (Utami et al., 2019a; Martínez Barrio et al., 2025). Interpretation is understood as the process of constructing meaning from available data or evidence (Utami et al., 2019b); analysis as the ability to break down information into its components and identify relationships between propositions (Sujatha Priyadharsini, 2025); inference as drawing justifiable conclusions from existing premises (Susandi, Sa'dijah and As'ari, 2019); evaluation as assessing the credibility of sources, arguments, and criteria used (Castle, 2011); and explanation as the ability to articulate reasoning structures and justifications coherently (García Medina et al., 2020). Thus, CTS are not only about "what" answers students provide, but also about "how" and "why" those answers are constructed.

Understanding CTS as an epistemic practice has important methodological implications. First, CTS measurement instruments must assess not only the accuracy of final answers but also the underlying justification process to ensure construct validity (Sujatmika et al., 2025). Second, comparisons of CTS across contexts, for example across regions, schools, or curricula, need to consider local epistemic cultures, including classroom discourse patterns, assessment methods, and curricular emphases that may facilitate or constrain certain critical thinking practices (Fadillah and Tanjung, 2025). In the context of Indonesian education, particularly at the junior high school level, learning practices that remain predominantly oriented towards memorisation and single-answer responses can hinder the development of CTS dimensions such as analysis and explanation (Billah and Masykuri, 2021).

Based on this rationale, the instrument development and interpretation of the results in this study were explicitly linked to epistemic criteria. The item design and scoring rubric were intended to capture variations in students' reasoning practices, not only their mastery of specific content. This approach allows differences in scores across CTS dimensions to be interpreted as reflecting authentic variations in students' critical thinking practices rather than artefacts of differences in material context or question format. With this theoretical framing, the study not only maps students' CTS levels descriptively but also provides conceptual meaning to the patterns of differences that emerge across CTS dimensions.

This epistemic perspective also helps explain the relevance of CTS to efficiency and responsibility in education and science. Critical thinking supports responsibility because it enables learners to assess evidence, question unsupported claims, and justify decisions in ways that are intellectually accountable and socially responsible. In contemporary education, this is especially important in helping students respond critically to misinformation, biased reasoning, and scientifically weak claims. At the same time, a dimensional understanding of critical thinking supports educational efficiency. When educators know which dimensions are relatively strong and which remain underdeveloped, learning strategies, assessment designs, and professional development efforts can be directed more precisely. Thus, the measurement of critical thinking dimensions is not only theoretically meaningful but also practically relevant for making educational interventions more targeted, resource-conscious, and responsible.

MATERIALS AND METHODS

Research design

This study employed a cross-sectional survey design to examine the profile of junior high school students' CTS, with students serving as the unit of analysis. A survey method was selected to obtain a comprehensive and accurate depiction of students' actual conditions in a natural educational context. As a descriptive study, the survey aimed to describe the sample's characteristics systematically and accurately. The findings from the sample were subsequently generalised to the broader population.

Population and sample

The population of this study consisted of all junior high school students in Bali Province, Indonesia, across both public and private schools. The total population was N = 188,999 students (Badan Pusat Statistik, 2024), distributed across eight regencies and one city. The sample size was estimated using Slovin's formula (McMillan, 2016), which is commonly applied in large-population survey research to determine the minimum required sample based on a specified margin of error. The formula is presented as follows:

$$n = \frac{N}{1 + Ne^2} = \frac{154{,}378}{1 + 154{,}378 \cdot (0.5)^2} = 384 \qquad (1)$$

where n = sample size, N = population size, and e = margin of error. In this study, a 5% margin of error (e = 0.05) was used, which aligns with standard practice in educational survey research.

Using this formula, the minimum required sample size was n = 384. However, to strengthen proportional representation across all regencies and the city in Bali Province, and to minimise the risk of sampling bias, the final sample comprised 403 students. This approach ensured that the sample adequately reflected the demographic and geographic distribution of the broader population.

Sampling techniques

A multistage random sampling technique was used to select the research sample from the large target population. This technique was chosen because it can accommodate regional diversity and variation in student characteristics in Bali Province. In the first stage, clusters were determined based on eight regencies and one city. In the second stage, schools in each cluster were randomly selected using cluster random sampling. After the schools had been determined, the third stage involved randomly selecting class levels from each school. This selection process helped ensure proportionality, so that the sample reflected the population distribution fairly. Thus, the study's results can describe students' CTS profiles more accurately and representatively. The sample structure is shown in Table 1.

Characteristics	Full sample	Percentage (%)
Gender		
Boys	178	44.17
Girls	225	55.83
Grade		
Seventh	143	35.48
Eighth	182	45.16
Ninth	78	19.36
Age		
11 years	3	0.75
12 years	91	22.58
13 years	170	42.18
14 years	108	26.80
15 years	31	7.69
Regencies/City		
Badung	57	14.14
Bangli	25	6.20
Buleleng	73	18.11
Denpasar	74	18.36
Gianyar	47	11.66
Jembrana	29	7.20
Karangasem	45	11.17
Klungkung	18	4.47
Tabanan	35	8.68

Table 1: Sample structure (source: own calculation)

Research instruments

The research instrument used in this study was a CTS test. This test was developed by the authors in previous studies. The CTS test blueprint is shown in Table 2. The test demonstrated content validity and had a Cronbach's alpha reliability coefficient of 0.920 (Redhana and Sudiana, 2015).

Dimensions	Item numbers (*k*)	Number of questions
Evaluation (CTS1)	1 – 10	10
Interpretation (CTS2)	11 – 20	10
Analysis (CTS3)	21 – 30	10
Inference (CTS4)	31 – 41	11
Explanation (CTS5)	42 – 50	9

Table 2: CTS test blueprint (source: own calculation)

Data collection

The paper-based test was distributed to schools and administered by the teachers who taught the sampled classes (the units of analysis). Before distributing the test to the students, the teachers were trained in how to administer it. The test was administered over 90 minutes. The test administration procedure required students to read the instructions first, check the number of questions, and then begin the test. Students could answer the questions in any order, from the easiest to the most challenging. While students were answering the questions, the teacher supervised them to ensure that they completed the test honestly. After the test administration, the teacher collected the tests and the students' answer sheets. The researcher collected the tests and students' answer sheets from the teachers the next day.

Data analysis

The data obtained in this study consisted of scores from the junior high school students' CTS test. These scores represent each student's level of mastery of CTS based on the test results. Furthermore, students' average scores were analysed and classified according to the score conversion guidelines. The classification guidelines are presented in detail in Table 3 as a reference for interpreting students' CTS achievements.

The raw score for each student on each CTS dimension was converted to a proportional score ranging from 0 to 1 to standardise interpretation across dimensions with different item counts. The conversion was performed using the following formula:

$$\text{Proportional score} = \frac{\text{Student´s row score}}{\text{Maximum possible score}} \qquad (1)$$

Mean score	Category
0.00 – 0.20	Very low
0.21 – 0.40	Low
0.41 – 0.60	Moderate
0.61 – 0.80	High
0.81 – 1.00	Very high

Table 3: Guidelines for converting mean scores into categories (scale of 0–1) (source: own calculation)

This proportional transformation is widely used in educational measurement because it produces comparable scores across dimensions with unequal numbers of items and facilitates interpretation using a standard scale (0–1). The category labels in Table 3 were based on these proportional scores.

These scores were processed using descriptive and inferential statistics. To answer the first research question "*What is the profile of the CTS of junior high school students in Bali Province, Indonesia?*", the data were processed using descriptive statistics, with the results presented as means and standard deviations. To answer the second research question—whether students' CTS differed across dimensions—the data were analysed using repeated-measures ANOVA. Before the ANOVA was carried out, assumption tests, including the normality test and Mauchly's test of sphericity, were conducted. If the sphericity assumption was violated, the Greenhouse–Geisser correction was applied. All tests were conducted using SPSS (IBM Corp.) at a significance level of 5%.

RESULTS

Profile of students' CTS

Table 4 presents the profile of students' CTS across dimensions and overall. The overall mean score was 0.453 (45.3%), indicating that students' CTS remained below 60%. Across dimensions, CTS1 had the highest mean score, at 0.528 (52.8%), followed by CTS2, at 0.502 (50.2%); CTS4, at 0.469 (46.9%); CTS3, at 0.393 (39.3%); and CTS5, at 0.373 (37.3%). These results show variation in students' performance across the five CTS dimensions.

Dimensions	*k*	Mean	*SD*
CTS1	10	0.528 (52.8%)	0.207
CTS2	10	0.502 (50.2%)	0.204
CTS3	10	0.393 (39.3%)	0.190
CTS4	11	0.469 (46.9%)	0.225
CTS5	9	0.373 (37.3%)	0.200
Overall	50	0.453 (45.3%)	0.205

Note. k = number of items; Mean = sample mean score; SD = standard deviation

Table 4: Profile of students' CTS by dimension and overall (scale of 0–1) (source: own calculation)

Differences across CTS dimensions

As shown in Table 4, mean scores differed across CTS dimensions. The highest mean score was found in CTS1 (0.528; 52.8%), whereas the lowest mean score was recorded for CTS5 (0.373; 37.3%). To examine whether these differences were statistically significant, repeated-measures analysis was conducted after assumption testing.

Before the repeated-measures analysis, assumption testing was conducted. The results of the Shapiro–Wilk test are presented in Table 5. All CTS dimensions yielded p-values below 0.05. However, the skewness and kurtosis values remained within an acceptable range, so the analysis proceeded to the sphericity test.

CTS Dimension	*n*	*W* Statistic	*p*-value
CTS1	403	0.961	< 0.001
CTS2	403	0.950	< 0.001
CTS3	403	0.950	< 0.001
CTS4	403	0.947	< 0.001
CTS5	403	0.934	< 0.001

Table 5: Results of the Shapiro–Wilk normality test for CTS dimensions (source: data processed using SPSS (IBM Corp.))

Table 6 presents the results of Mauchly's test of sphericity. The test was not significant, $W = 0.963$, $\chi^2(9) = 15.303$, $p = 0.083$, indicating that the sphericity assumption was met.

After the assumptions had been examined, repeated-measures ANOVA and pairwise comparison tests were conducted to examine differences in mean scores across dimensions. Table 7 shows that the differences were statistically significant, $F(4, 1608) = 88.922$, $p < 0.001$, with an effect size of $\eta p^2 = 0.181$.

To identify which dimensions differed significantly, Bonferroni-adjusted pairwise comparisons were performed. The results are presented in Table 8.

Effect	Mauchly's *W*	χ^2	*df*	*p*-value
CTS dimensions	0.963	15.303	9	0.083

Table 6: Mauchly's test of sphericity for CTS dimensions (source: data processed using SPSS (IBM Corp.))

Effect	*df*	*F*	*p*-value	ηp^2
CTS dimensions	(4, 1608)	88.922	< 0.001	0.181

Table 7: Repeated-measures ANOVA results for CTS dimensions (sphericity assumed) (source: data processed using SPSS (IBM Corp.))

Comparison	Mean Difference	*t*	*p*-value	Cohen's *dz*
CTS1 – CTS2	0.026	2.75	0.062	0.137
CTS1 – CTS3	0.135	13.17	< 0.001	0.656
CTS1 – CTS4	0.059	5.72	< 0.001	0.285
CTS1 – CTS5	0.157	14.76	< 0.001	0.735
CTS2 – CTS3	0.109	10.86	< 0.001	0.541
CTS2 – CTS4	0.033	3.22	0.014	0.160
CTS2 – CTS5	0.130	11.98	< 0.001	0.597
CTS3 – CTS4	−0.076	−7.61	< 0.001	−0.379
CTS3 – CTS5	0.021	1.99	0.377	0.099
CTS4 – CTS5	0.097	9.88	< 0.001	0.492

Table 8: Bonferroni-adjusted pairwise comparisons among CTS dimensions (source: data processed using SPSS (IBM Corp.))

The pairwise comparisons showed that most pairs of CTS dimensions differed significantly. The largest mean differences were found between CTS1 and CTS5 and between CTS1 and CTS3. By contrast, the comparisons between CTS1 and CTS2 and between CTS3 and CTS5 were not statistically significant. Overall, CTS1 and CTS2 had the highest mean scores, CTS4 occupied an intermediate position, and CTS3 and CTS5 had the lowest mean scores.

DISCUSSION

The results of this study indicate that the CTS of junior high school students in Bali Province remain relatively low. These findings reflect not only weak numerical achievement but also more fundamental epistemic challenges in everyday learning practices. CTS, which encompass the abilities to evaluate, interpret, analyse, draw inferences, and explain, require complex and multilevel cognitive processes. Persistently low average scores across these dimensions suggest that students are not yet accustomed to engaging in learning activities that demand in-depth reasoning, reflection, and evidence-based justification.

Students' low CTS can be understood as a consequence of learning environments that remain predominantly oriented towards memorisation and superficial understanding. Instructional practices that emphasise information reproduction while providing limited opportunities for exploration, analysis, and logical argumentation may hinder the development of CTS, particularly in the analysis and explanation dimensions, which require explicit elaboration of reasoning (Soufi and See, 2019). Importantly, CTS are not innate abilities but a set of skills that can be systematically taught, practised, and developed through appropriate instructional design (Papadopoulos and Bisiri, 2020; Bezanilla et al., 2021; Saenab et al., 2021).

The findings of this study are consistent with previous research in Indonesia, which has reported low CTS across different educational levels (Basri et al., 2019; Saputri et al., 2019; Marni et al., 2020; Sarwanto et al., 2021; Suryanti and Nurhuda, 2021). This consistency suggests that limited CTS are not merely an individual student issue but a systemic challenge related to curriculum design, instructional strategies, and assessment practices. Similar patterns have also been reported internationally, including in Malaysia (Ismail et al., 2019), the Netherlands (Van der Zanden et al., 2019), Australia (Gunawardena and Wilson, 2021), Spain (Cáceres et al., 2020), and Turkey (Palavan, 2020), indicating that the development of CTS remains a global concern in modern education.

Further analysis of differences across CTS dimensions provides important insights. The evaluation and interpretation dimensions yielded higher scores than analysis and explanation, indicating that students are relatively more capable of assessing information and understanding explicit meanings than of deconstructing arguments or articulating their own reasoning. Evaluation tasks may still be approached intuitively, relying on experience or explicit cues. In contrast, analysis and explanation require higher levels of metacognitive awareness and the ability to communicate reasoning logically and coherently.

Low achievement in the analysis and explanation dimensions also reflects students' limited exposure to open-ended reasoning tasks. When classroom assessments predominantly consist of multiple-choice questions with a single correct answer, students have few opportunities to explain their reasoning, connect concepts, or defend arguments. Consequently, their ability to analyse relationships among ideas and articulate justified explanations remains underdeveloped. These findings support the view that CTS can develop only when students are consistently engaged in cognitively demanding tasks that encourage reflection and reasoning (Gunawardena and Wilson, 2021; Li et al., 2023).

From an educational perspective, these findings have important implications. Teachers need to design instruction that emphasises not only content mastery but also students' thinking processes. Instructional approaches such as problem-based learning and project-based learning offer strategic alternatives by providing opportunities for students to analyse authentic problems, engage in discussion, and explain proposed solutions (Ulger, 2018; Seibert, 2021). In addition, assessment practices should be expanded to include essays, case analyses, or mini-projects that allow students to demonstrate their reasoning processes rather than merely selecting answers. At the policy level, these findings reinforce the importance of implementing the Independent Curriculum (Curriculum Merdeka) in ways that genuinely promote higher-order thinking skills, supported by sustained teacher professional development, adequate resources, and a school culture that values CTS.

These findings also have implications for efficiency and responsibility in education and science. In terms of efficiency, the dimensional differences identified in this study suggest that educational interventions should not be designed uniformly across all aspects of CTS. Because students showed relatively stronger performance in evaluation and interpretation but weaker performance in analysis and explanation, instructional emphasis can be directed more strategically towards the dimensions that require greater reinforcement. This would allow schools and teachers to use limited time, assessment opportunities, and professional resources more effectively. In terms of responsibility, strengthening CTS is part of education's obligation to prepare students to engage with knowledge claims in a careful, evidence-based, and ethically aware manner. In an era of widespread misinformation and rapid circulation of unverified content, promoting CTS is closely related not only to responsible educational practice but also to the broader responsibility of science education and schooling.

Overall, this study not only maps the level of CTS among junior high school students in Bali Province but also identifies specific dimensions that require greater instructional attention. The primary value of these findings lies in providing an empirical foundation for more targeted and meaningful educational interventions. By recognising that students' main weaknesses lie in analysis and explanation, educators and policymakers can design learning and assessment strategies that more effectively support the development of rational, reflective, and responsible thinking, which are essential capabilities in 21st-century education.

This research makes several significant contributions to educational studies and practice. It offers a comprehensive provincial-level mapping of students' CTS using a standardised, content-free instrument, providing a more representative picture than prior studies limited to smaller contexts. In addition, the dimension-based analysis deepens understanding of patterns of strength and weakness in students' CTS, thereby informing more focused instructional and policy interventions at the junior high school level.

Despite these contributions, several limitations should be considered when interpreting the findings. The study is limited to the geographical context of Bali Province, and the results should therefore be interpreted within the local educational context. Moreover, the cross-sectional design captures CTS at a single point in time and does not allow conclusions about development or causality. Finally, although the instrument demonstrated high reliability, reliance on written test performance may not fully capture students' CTS as enacted in authentic learning situations. Future research could address these limitations by expanding regional coverage, adopting longitudinal designs, and using qualitative or mixed-methods approaches.

CONCLUSION

This study shows that the CTS of junior high school students in Bali Province are generally still in the low category, with an average mastery level below 60%. Dimension-based analysis revealed significant differences among CTS dimensions, with evaluation and interpretation performing better than analysis and explanation. These findings indicate that students tend to be more capable of assessing and understanding information explicitly but still experience difficulties in conducting in-depth analytical reasoning and articulating their thought processes logically and structurally. This pattern reflects a more fundamental epistemic challenge in everyday learning practices, particularly in learning and assessment that remain predominantly oriented towards memorisation and single answers.

By providing a comprehensive provincial-level mapping of CTS using a standardised, content-free instrument, this study offers a strong empirical basis for developing more targeted and responsible learning strategies, assessments, and educational policies to strengthen junior high school students' CTS. In the context of 21st-century education, which is complex and characterised by massive information flows, strengthening CTS is no longer merely a normative goal but a fundamental need to equip the younger generation with rational thinking skills. Accordingly, the study contributes to the promotion of both efficiency and responsibility in education by providing empirical evidence that can guide more targeted resource allocation, more focused instructional improvement, and more accountable efforts to strengthen students' CTS.

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Full research paper

THE MEDIATING ROLE OF DIGITAL CREATIVITY IN THE RELATIONSHIP BETWEEN ATTITUDES TOWARD DIGITALIZATION AND EDUCATIONAL MANAGEMENT INFORMATION SYSTEMS

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ABSTRACT

In the era of digital transformation, the success of educational management systems increasingly depends not only on technology but also on users' attitudes and creativity. Despite growing research on technology adoption in education, few studies have examined how attitudes toward digitalization (ATD) and digital creativity (CTD) interact to influence the efficiency, effectiveness, and responsible implementation of Educational Management Information Systems (EMIS) in educational institutions. To address this gap, the present study investigated how CTD mediates the relationship between ATD and EMIS. A total of 347 respondents participated in the study by completing an online questionnaire. Structural Equation Modeling (SEM) was employed to test four hypotheses. The results revealed that ATD significantly enhanced EMIS performance both directly and indirectly through CTD. Furthermore, CTD emerged as a critical mediator, indicating that while a positive digital attitude provides the motivational foundation for technology adoption, creativity transforms this attitude into innovative, efficient, and contextually responsible EMIS applications. The study highlights how fostering positive attitudes and digital creativity among users can improve operational efficiency and promote responsible management practices in educational settings.

KEYWORDS

Attitude toward digitalization, digital creativity, educational management information systems, higher education, operational efficiency

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Highlights

- *Attitude toward digitalization has a significant positive effect on educational management information systems.*
- *Digital creativity positively predicts educational management information system outcomes.*
- *Attitude toward digitalization significantly predicts digital creativity.*
- *Digital creativity mediates the relationship between attitude toward digitalization and educational management information systems.*

INTRODUCTION

The development of information technology has brought significant changes to education, particularly in higher education. Digitalization has become a crucial element in managing educational systems more efficiently and transparently (Saner et al., 2020). One relevant innovation is the implementation of Educational Management Information Systems (EMIS) in universities, which are designed to support the administrative, academic, and operational management of educational institutions (Martins et al., 2019; Shah, 2014). Effective EMIS implementation can enhance operational efficiency and improve the quality of educational services (Al-Ababneh & Alrhaimi, 2020; El-Ebiary et al., 2018). However, successful EMIS implementation depends not only on the technology itself but also on users' attitudes toward digitalization and their level of digital creativity.

Attitudes toward digitalization play a vital role in driving the adoption of new technologies in education (Wang et al., 2024). These attitudes reflect individuals' acceptance, readiness, and confidence in embracing digital transformation. Resistance to digitalization remains a major challenge, particularly in higher education settings (Blin & Munro, 2008), and a lack of readiness to adopt digital technology can hinder the effectiveness of EMIS. Nevertheless, the adoption and use of digital technology in educational systems provide opportunities to advance education worldwide (Kashada et al., 2018).

In addition to attitudes toward digitalization, digital creativity is another key factor. Digital creativity refers to an individual's ability to use digital technologies to generate innovative and useful solutions, foster creativity, and produce high-quality content (Shao et al., 2022). This capability not only supports technology-based learning but also strengthens the use of EMIS as a platform for more interactive and collaborative educational experiences. Importantly, digital creativity may mediate the influence of attitudes toward digitalization on EMIS performance, a relationship that has not been fully explored in higher education contexts. Individuals with positive attitudes toward digitalization are more likely to engage creatively with digital tools and generate innovative solutions that enhance EMIS effectiveness. Understanding this mediating role can clarify how attitudes translate into actual EMIS performance and provide practical insights for designing digital competency programs and strategies to improve system adoption in universities.

Despite advances in EMIS adoption, several Indonesian universities still face obstacles, including low digital creativity and resistance to digitalization. Junus et al. (2021) found that although educators possess basic technical skills and adapt quickly to Learning Management Systems, many rely on tactical rather than strategic solutions. Their ability to teach online classes effectively is often underutilized because they lack confidence in achieving learning objectives through these platforms. Similarly, Afrianty et al. (2022) found that digital orientation significantly affects individuals' digital capabilities, which in turn influence productivity. These findings highlight a gap between technological potential and the readiness of human resources to use it effectively.

Previous studies have shown that attitudes toward digitalization and digital creativity influence technology adoption and performance outcomes. For example, Eaglestone et al. (2007) indicated that integrating information systems and creativity supports creative work activities. Likewise, Muller and Ulrich (2013) emphasized that creativity can be enhanced by considering information system components and work environments. Technology use has also been shown to improve administrative efficiency and overall educational quality, thereby strengthening positive perceptions of digital information management systems (Haleem et al., 2022; Timotheou et al., 2023).

Although several studies have examined attitudes toward digitalization and digital creativity separately in relation to EMIS, few have integrated all three variables to investigate how CTD mediates the relationship between ATD and EMIS performance. Addressing this gap is crucial for understanding how positive ATD translates into effective EMIS use and for identifying the mechanisms that enhance system adoption in higher education. Therefore, this study aims to analyze the influence of attitudes toward digitalization on EMIS, with digital creativity as a mediating factor, in higher education institutions. Practically, the findings are expected to guide universities in developing effective EMIS strategies and digital competency programs for staff. Theoretically, the study contributes to a conceptual model that integrates attitudes and digital creativity, providing a deeper understanding of the human and technological factors that drive successful EMIS adoption.

THEORETICAL FRAMEWORK

Attitudes toward digitalization and educational management information systems

Attitudes toward digitalization refer to individuals' perceptions, beliefs, confidence, and willingness to engage with and adopt digital technologies (Vasilescu et al., 2020). A positive attitude toward the adoption of digital technologies can enhance the efficiency and effectiveness of academic data management, administrative tasks, and communication among students, teachers, and parents. Vlachopoulos et al. (2023) showed that digitalization can affect educational management, including curriculum development. To implement institutional management systems accurately and effectively in schools, institutional actors, particularly teachers, must have a positive and confident attitude toward using these systems, as such attitudes can motivate them to integrate digital management tools into their routine work (Wei et al., 2016).

Similarly, a positive attitude toward digital technology is a critical factor that can differentiate educational management systems (Mwangi–Ng'ayo et al., 2023). Globally, other supporting variables for educational management systems, such as access to education, infrastructure, and the quality of education, must also be addressed to ensure equitable access to education, reduce dropout rates, improve teaching quality, and enhance learning environments worldwide (OECD, 2012). Sánchez-Franco et al. (2009) also support the importance of attitudes toward ICT and digitalization. Hakkarainen et al. (2000) investigated students' attitudes toward the importance of ICT in their studies and future lives and found that female students, particularly younger ones, tended to have more positive attitudes toward digitalization. This indicates that people with positive attitudes toward digitalization are generally more adaptable and better able to use various features of educational management systems to support learning goals. In contrast, negative attitudes or resistance to technology can prevent information management systems from reaching their full potential in improving educational quality. Therefore, attitudes toward digitalization play a significant role in the success of educational management information systems.

Digital creativity and educational management information systems

Digital creativity and educational management information systems share a synergistic relationship that can enhance the quality of education. Digital creativity refers to an individual's ability to generate diverse and innovative ideas using digital technology (M. R. Lee & Chen, 2015). While digital skills support the development of digital creativity, creativity extends beyond technical proficiency to include originality, experimentation, and problem-solving using digital technologies (M.-H. Nguyen et al., 2023). This capacity plays a crucial role in implementing and optimizing EMIS, helping institutions build adaptive and responsive management systems.

Digital creativity plays a positive role in educational management systems. A study by Massaro et al. (2012) on the role of creativity in management control systems found that, in the early stages of the creative process, digital creativity enables the use of technology-based diagnostic and boundary tools to identify, analyze, and map problems more efficiently. Digital technologies can provide data, visualization, and simulations that accelerate the resolution of structured problems. Meanwhile, during the design phase, the dynamic tension between interactive and diagnostic systems is often considered the most effective approach. In addition, a literature review by Di Vaio et al. (2021) on digital innovation in knowledge management systems found that digital innovation contributes significantly to management systems. Specifically, the study explored the relationship between innovation and sustainability, revealing that digital transformation tools contribute to the creation of long-term value. Likewise, digital creativity has been recognized as one of the keys to successful management (Lee-Partridge et al., 2000; Seidel et al., 2010). Therefore, digital creativity has a positive impact on management systems.

Attitudes toward digitalization and digital creativity

Positive attitudes toward digitalization are a key factor influencing digital creativity. Individuals who feel comfortable and confident using digital tools are more likely to engage in technological experimentation, a critical component of the creative process (Margaryan et al., 2011). Such attitudes foster a desire to learn and improve digital skills, thereby facilitating the generation of innovative ideas. Access to appropriate technology, combined with a positive attitude, creates a synergy that further enhances digital creativity (Van Deursen et al., 2021). Digital creativity has become increasingly important in the modern era because it supports innovation and sustainability across various sectors, from education to industry. Digitalization enables creative problem-solving through tools such as AI, big data, and collaborative platforms (Panori et al., 2021). However, the ability to take advantage of these opportunities depends on the extent to which individuals develop supportive attitudes toward technology. In this sense, attitudes toward digitalization function not only as indicators of readiness for technology adoption but also as catalysts for innovative uses of technology.

The positive impact of attitudes toward digitalization on digital creativity can be further understood through the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), which explain how individuals' perceived usefulness, perceived ease of use, and performance expectancy shape their engagement with technology (Alyoussef, 2022; Ayaz & Yanartaş, 2020; Venkatesh et al., 2003). Empirical studies in higher education, such as research on flipped classrooms, show that students' positive attitudes toward digital tools and expectations of performance improvements increase their willingness to adopt and effectively use technology, which in turn enhances their creative engagement and problem-solving abilities (Al-Emran & Teo, 2020; Alyoussef, 2022). Similarly, Lee and Erdogan (2007) found that attitudes toward technology significantly predicted students' creative potential, highlighting that positive perceptions and readiness to use technology are critical for fostering creativity. This theoretical and empirical evidence suggests that ATD is not only a readiness factor but also a driver of digital creativity, providing a strong foundation for understanding how individuals transform positive attitudes into innovative applications of digital technologies.

Mediating role of digital creativity

Digital creativity serves as a key mediator between attitudes toward digitalization and the successful implementation of EMIS. Individuals with positive attitudes toward digitalization are more likely to experiment with and adopt digital tools in novel ways, thereby enhancing their creative engagement (Safavi & Ghazinoory, 2024; Vasilescu et al., 2020). Drawing on TAM and UTAUT principles, positive attitudes increase users' performance expectations and confidence in technology use, which in turn fosters creative problem-solving and innovation when interacting with digital systems (Vankúš, 2024). Within EMIS, digital creativity enables users to develop innovative solutions that address administrative and educational challenges effectively, ensuring that technology adoption is not only functional but also adaptive and forward-looking.

Furthermore, digital creativity functions as a bridge between the potential of digital technology and the specific needs of the education sector. While attitudes toward digitalization influence willingness to engage with technology, users' digital creativity translates this willingness into actionable and innovative practices (Janse Van Rensburg et al., 2022; Shao et al., 2022). In the context of educational management systems, digital creativity empowers users to identify and address challenges through unique, technology-driven approaches, thereby strengthening the overall effectiveness and sustainability of EMIS. This mediating role not only clarifies the mechanism behind successful technology integration but also highlights the importance of fostering both positive digital attitudes and creative competencies through institutional policies, training programs, and supportive digital ecosystems.

Hypotheses

Our model is presented in Figure 1. We hypothesize that (H1) ATD is positively related to EMIS; (H2) CTD positively contributes to EMIS; (H3) ATD positively predicts CTD; and (H4) CTD mediates the relationship between ATD and EMIS.

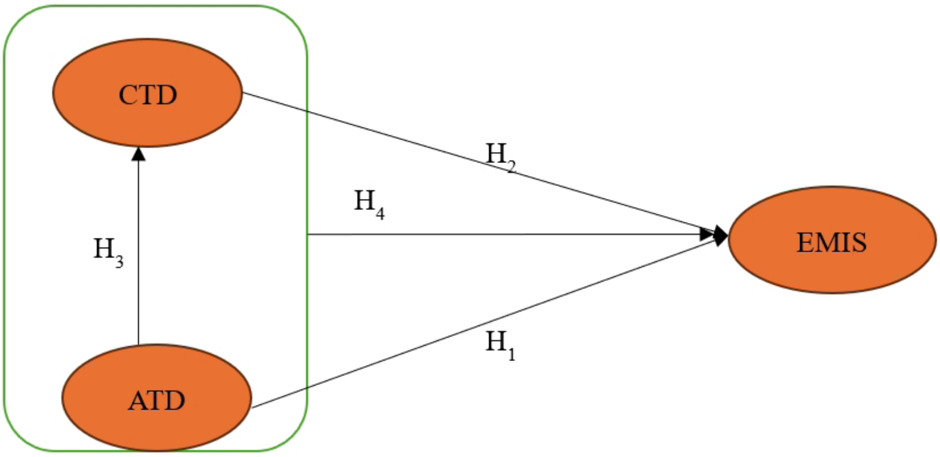

Figure 1: Conceptual model of the relationship between digital creativity (CTD), attitude toward digitalization (ATD), and educational management information systems (EMIS) (Source: own calculation)

MATERIALS AND METHODS

Participants

This study involved 347 respondents from higher education institutions in Indonesia, with 36% identifying as female and 64% as male, representing both public and private universities. The respondents had a mean age of 39.30 years (*SD* = 7.75; *SE* = 0.42). A cross-sectional research design was employed (Daniels, 2011). Participants were selected using a simple random sampling technique from a list of eligible respondents affiliated with higher education institutions, including academic staff, administrative personnel, and educational practitioners who met the study's inclusion criteria (T. D. Nguyen et al., 2021). Data were collected using an online questionnaire distributed to the randomly selected participants. Ethical approval was obtained from the Research Ethics Committee of Universitas Islam Negeri Raden Intan Lampung (No. 3/2025), and informed consent was secured from all participants before data collection. The demographic characteristics of the respondents are summarized in Table 1.

Demographics		Frequency	Percentage (%)
Gender	Female	122	36.0
	Male	222	64.0
Type university	Public	286	82.4
	Private	61	17.6
Residence	City	309	89.0
	Suburb	38	11.0
Education level	Bachelor's degree	2	0.60
	Master's degree	269	77.5
	Doctor degree	76	21.9
Work experience (year)	1-5	108	31.1
	6-10	78	22.5
	11-15	47	13.5
	16-20	53	15.3
	21-25	39	11.2
	26-30	4	1.20
	31-35	11	3.20
	36-40	6	1.70
	>40	1	0.30

Table 1: Demographic characteristics of the research sample (Source: own calculation)

Instruments

Attitude Toward Digitalization. To evaluate Attitude Toward Digitalization, we adopted a scale from Janschitz and Penker (2022). Sample items include the following five statements: "If the Internet and digital devices were gone tomorrow, it would have a negative impact on my daily life," "I often use the Internet longer than I intended to," "I am always interested in the latest trends in the digital environment (e.g., new equipment, new software, new apps)," "A life without the Internet would be unimaginable for me," and "When I need information, I search the Internet first." the original scale has been validated, with a Cronbach's alpha of 0.63, and the model fit indices are as follows: χ^2 = 58.5, *df* = 5, *RMSEA* = 0.049 [0.038; 0.061], *CFI* = 0.98, and *SRMR* = 0.022.

Respondents were asked to respond using a 7-point Likert scale, ranging from 1 = strongly disagree to 7 = strongly agree. For the purposes of this study, the questionnaire was revalidated within the sample context to assess its validity and reliability.

Digital Creativity. This scale was adapted from Van Laar et al. (2019) and consists of six items. Sample items include "At work, how often do you give a creative turn to existing processes using the Internet?" and "At work, do you use the Internet to generate innovative ideas for your field?" the original scale demonstrated good reliability, with a Cronbach's alpha of 0.89. Participants responded using a 7-point Likert scale, ranging from 1 = never to 7 = always. For the purposes of this study, the questionnaire was revalidated within the sample context to determine its validity and reliability.

Educational Management Information System. This scale was adapted from Martins et al. (2019) and consists of six subscales with a total of 28 items. Sample items include: System Quality: "Using my university EMIS is easy to learn," "Help functions are available and sufficient for using my university EMIS." Information Quality: "The information provided about the curricular units taught is complete," "The information provided about the curricular units taught is always up-to-date." Service Quality: "Email and other forms of online help are available in case of problems with using the system," "Teachers/EMIS support staff are helpful for using the system." Use: "While using my university EMIS, I use available features to organize my content," "While using my university EMIS, I collaborate with my peers or teachers." User Satisfaction: "I like working with my university EMIS," "My university's EMIS makes work more interesting." Net Benefits: "My university EMIS encourages me to develop a positive attitude toward lifelong learning," "My university EMIS helps me to make connections between formal (i.e., structured learning within the school or faculty) and informal (i.e., unstructured learning occurring in everyday life) learning experiences." the original scale has been validated, showing discriminant validity with Heterotrait-Monotrait (HTMT) ratios ranging from 0.512 to 0.824. Cronbach's alpha values ranged from 0.854 to 0.910, and composite reliability (CR) values ranged from 0.906 to 0.939. In this study, respondents used a 7-point Likert scale, ranging from 1 = strongly disagree to 7 = strongly agree. For research purposes, the questionnaire was validated in the context of the sample to determine its validity and reliability.

Data analysis

In this study, data analysis was conducted using several software tools, including the Statistical Package for the Social Sciences (SPSS) version 29, Smart PLS 4, and R. SPSS was used to conduct descriptive statistical analysis and correlation tests. The validity and reliability of the items were examined using Smart PLS 4 through Confirmatory Factor Analysis (CFA), along with an evaluation of model fit (Jomnonkwao and Ratanavaraha, 2016). Model fit indices, including chi-square, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), Goodness of Fit Index (GFI), and Standardized Root Mean Square Residual (SRMR), were analyzed using accepted threshold values (Hair et al., 2021; Kline, 2015). For example, a CFI value greater than 0.90 indicates an adequate model, and an RMSEA value below 0.08 is considered satisfactory. Reliability was also assessed using Cronbach's alpha and composite reliability, with values above 0.70 indicating acceptable reliability (Habók & Magyar, 2018; Suherman & Vidákovich, 2024a, 2025). Discriminant validity was examined using the Heterotrait-Monotrait ratio (HTMT), with an acceptable threshold of 0.85 (Kline, 2015). Structural Equation Modeling (SEM) was used to test the research hypotheses. Additional data visualization was carried out in R using specialized plots (e.g., ggplot) to present the descriptive statistical results.

RESULTS

Reliability and validity of the data

The reliability and validity of the measurement model were evaluated using outer loadings, Cronbach's alpha, composite reliability, and Average Variance Extracted (AVE), as summarized in Table 2. One item from the ATD construct (ATD1) and seven items from the EMIS construct (EIQ4, EIQ5, ENB5, EQS4, EQS5, EUS4, and EUS5) were removed due to factor loadings below the acceptable threshold of 0.40. The remaining items demonstrated outer loadings above 0.60, indicating acceptable indicator reliability. All constructs exhibited Cronbach's alpha and composite reliability values above 0.70, supporting internal consistency, while AVE values for each latent variable exceeded 0.50, suggesting satisfactory convergent validity (Hair et al., 2021; Henseler et al., 2015). Specifically, attitude toward digitalization had a Cronbach's alpha of 0.801 and AVE of 0.505, digital creativity showed values of 0.877 and 0.545, and EMIS achieved values of 0.962 and 0.550, respectively. Overall, these results demonstrate that the measurement model has acceptable reliability and validity, providing a strong foundation for further structural equation modeling.

Discriminant validity

Discriminant validity was assessed using the Heterotrait-Monotrait Ratio (HTMT), as recommended by Hair et al. (2021). As shown in Table 3, all HTMT values were below the conservative threshold of 0.85, indicating satisfactory discriminant validity among the constructs. The HTMT values ranged from 0.737 (between attitude toward digitalization and digital creativity) to 0.817 (between digital creativity and EMIS). These results suggest that each construct is empirically distinct and captures a unique aspect of the model.

Descriptive statistics

Table 4 displays the descriptive statistics of the three core variables. The mean (*M*) scores for all variables ranged from 4.07 to 4.28 on a 5-point Likert scale, indicating generally favorable responses from participants. The visualization is shown in Figure 2. The standard deviation (*SD*)

Laten Variables	Item Code	Outer loads	Cronbach's alpha	Composite Reliability	AVE
Attitude towards digitalization			0.801	0.799	0.505
	ATD2	0.701			
	ATD3	0.765			
	ATD4	0.611			
	ATD5	0.756			
Digital creativity			0.877	0.878	0.545
	CTD1	0.762			
	CTD2	0.795			
	CTD3	0.724			
	CTD4	0.724			
	CTD5	0.716			
	CTD6	0.703			
Educational management information system			0.962	0.962	0.550
	EIQ1	0.699			
	EIQ2	0.734			
	EIQ3	0.747			
	ENB1	0.710			
	ENB2	0.785			
	ENB3	0.724			
	ENB4	0.745			
	EQS1	0.736			
	EQS2	0.752			
	EQS3	0.735			
	ESQ1	0.757			
	ESQ2	0.742			
	ESQ3	0.741			
	ESQ4	0.725			
	ESU1	0.734			
	ESU2	0.734			
	ESU3	0.733			
	ESU4	0.789			
	EUS1	0.753			
	EUS2	0.718			
	EUS3	0.769			

Table 2: Factor loadings and convergent validity among variables (Source: own calculation)

	ATD	CTD	EMIS
Attitude towards digitalization	-		
Digital creativity	0.737	-	
Educational management information system	0.793	0.817	-

Table 3: Discriminant validity: Heterotrait-Monotrait Ratio (HTMT) (Source: own calculation)

values ranged from 0.75 to 0.94, indicating moderate data dispersion. Regarding data normality, Kline (2015) suggested that skewness values should not exceed |3| and that kurtosis should remain below |10|. The skewness values (ranging from -0.91 to -0.59) and kurtosis values (0.01 to 0.45) in this study were well within these acceptable limits, confirming that the data were approximately normally distributed. To assess multicollinearity, Variance Inflation Factor (VIF) scores were examined for all indicators. The VIF values ranged between 1.45 and 2.93, well below the critical threshold of 5, indicating that multicollinearity is not a concern and that the independent variables used in the model do not exhibit redundant linear relationships.

Together, the descriptive statistics, normality checks, and multicollinearity checks confirm that the data are suitable for SEM analysis. The approximately normal distributions and acceptable VIF scores provide confidence that the structural relationships among latent variables can be reliably estimated, supporting the validity of the subsequent path analysis and mediation testing.

Variables	*M*	*SD*	Skewness	Kurtosis
Attitude towards digitalization	4.07	0.94	-0.79	0.06
Digital creativity	4.28	0.78	-0.91	0.45
Educational management information system	4.23	0.75	-0.59	0.01

Table 4: Descriptive statistics and data normality (Source: own calculation)

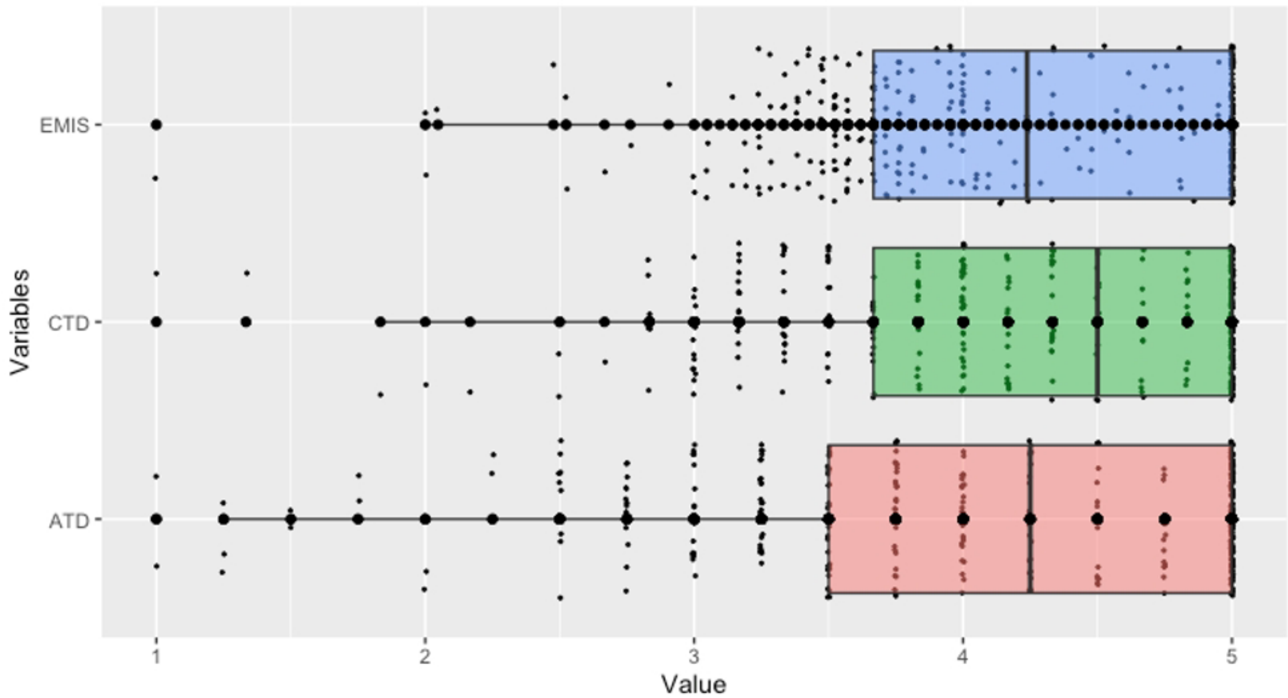

Figure 2: Ggplot descriptive statistics of variables (Source: own calculation)

Evaluation of structural equation modeling

SEM was used to test the study hypotheses (Fig. 3). The model fit indices were as follows: χ^2 ($df = 31$) = 1084.383, $p < 0.001$, *CFI* = 0.90, *TLI* = 0.91, *RMSEA* = 0.06, and *SRMR* = 0.03. According to established criteria (Hu & Bentler, 1999), acceptable values are *CFI* and *TLI* above 0.90 and *RMSEA* and *SRMR* below 0.08. The values obtained met these thresholds, indicating that the model demonstrated satisfactory fit. The coefficient of determination showed that CTD and ATD together explained 65.3% of the variance in EMIS ($R^2 = 0.653$), while ATD accounted for 38.7% of the variance in CTD ($R^2 = 0.387$).

Path analysis results indicated significant relationships among the variables. Attitudes toward digitalization had a direct positive effect on EMIS (coefficient = 0.378, $p < 0.001$), suggesting that individuals with more positive attitudes toward digital technology are more likely to use and support EMIS effectively in higher education. Digital creativity was positively related to EMIS (coefficient = 0.517, $p < 0.001$), indicating that higher creative engagement with digital tools leads to better utilization and innovation within EMIS. In addition, attitudes toward digitalization were directly associated with digital creativity (coefficient = 0.622, $p < 0.001$), showing that positive digital attitudes significantly foster the creative use of technology.

To examine the mediating role of digital creativity between attitudes toward digitalization and EMIS, a bootstrap procedure with 5000 resamples was conducted. The results indicated a significant indirect effect (coefficient = 0.321, $p < 0.001$), meaning that approximately one-third of the total effect of attitudes toward digitalization on EMIS operates through digital creativity. In practical terms, this suggests that fostering positive attitudes toward digitalization not only directly improves EMIS adoption and performance but also indirectly enhances EMIS outcomes by promoting users' creative engagement with technology. Table 5 presents the total direct and indirect effects, highlighting that digital creativity acts as a meaningful mechanism that translates positive digital attitudes into more effective and innovative EMIS use.

The results indicate that attitudes toward digitalization exert a significant direct effect on both digital creativity and EMIS performance. Digital creativity also has a strong positive association with EMIS and functions as a significant mediator between ATD and EMIS, accounting for approximately one-third of the total effect. The measurement model demonstrated acceptable reliability and validity, and the structural model fit indices confirmed a good fit, with substantial variance explained for the key constructs. Overall, these findings underscore the importance of both positive digital attitudes and creative engagement with technology in driving effective EMIS adoption and utilization in higher education.

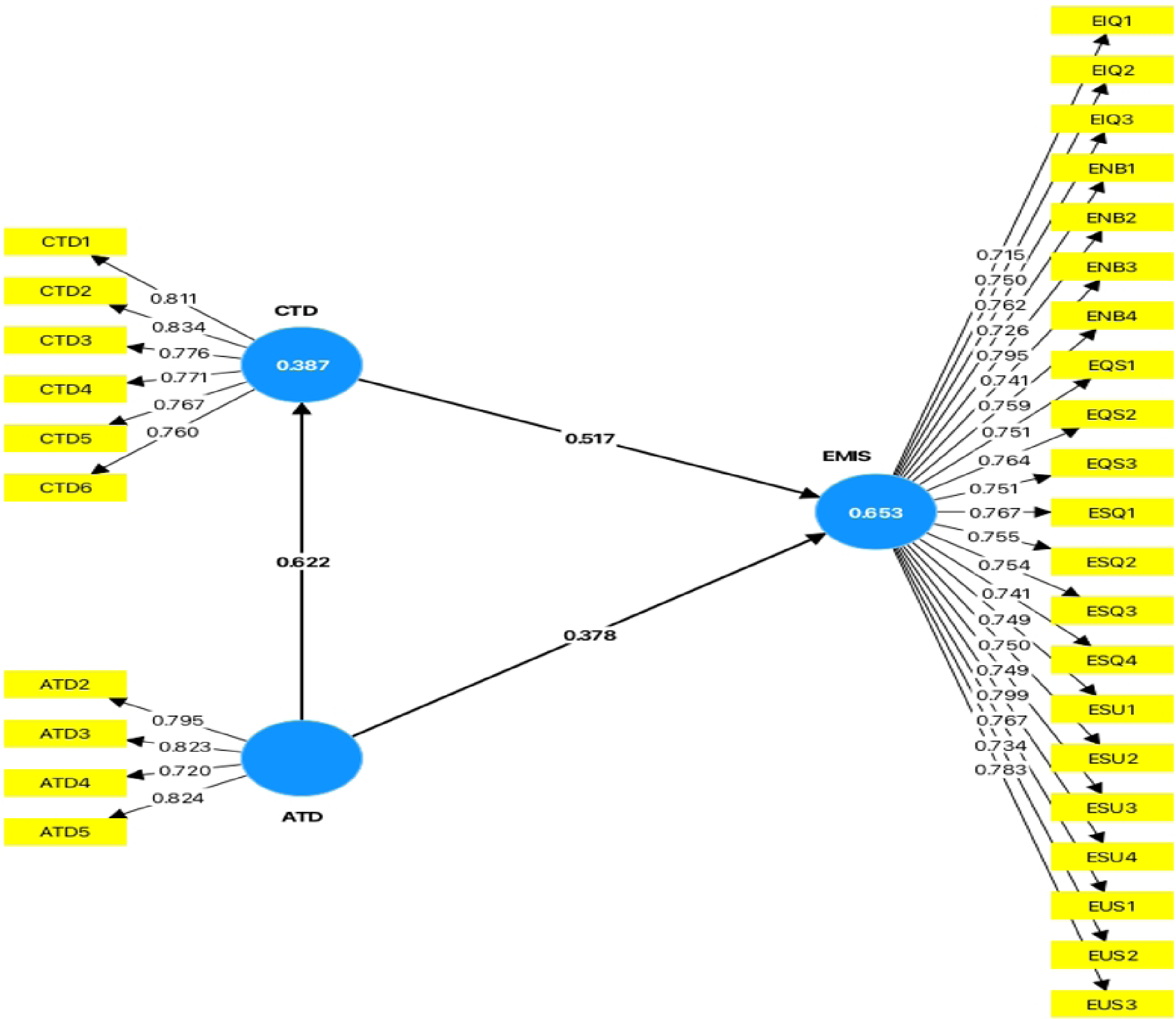

Figure 3: Standardized association between EMIS, CTD, and ATD (Source: own calculation)

	Original sample (*O*)	Sample mean (*M*)	Standard deviation (*STDEV*)	*T* statistics (|*O/STDEV*|)	*p* values
ATD -> CTD	0.622	0.624	0.047	13.273	< 0.001
ATD -> EMIS	0.378	0.376	0.073	5.179	< 0.001
CTD -> EMIS	0.517	0.520	0.085	6.080	< 0.001
ATD -> CTD -> EMIS	0.321	0.325	0.061	5.244	< 0.001

Table 5: Total direct and indirect effects among variables (Source: own calculation)

DISCUSSION

The findings of the current study indicate that ATD is positively associated with EMIS, supporting Hypothesis 1. This positive relationship highlights the importance of user attitudes in the acceptance and efficiency of digital tools within educational settings. For example, Gezer and Karagözoğlu (2023) found a significant relationship between teachers' levels of digital literacy and their attitudes toward distance education, suggesting that enhanced digital competencies lead to a more favorable disposition toward digital systems. Hadi et al. (2022) also support this view by showing how user satisfaction with online EMIS is influenced by users' attitudes toward these systems. Their research indicates that a positive attitude toward digital tools correlates with higher user satisfaction, thereby enhancing system effectiveness. This finding underscores that it is not only the technology itself but also users' perceptions of the technology that ultimately determine the success of its implementation in educational management. Consequently, EMIS initiatives that focus solely on technical infrastructure without addressing users' attitudes risk underutilization, resistance, or superficial compliance. When educators and administrators perceive digital systems as burdensome, misaligned with their needs, or imposed without adequate support, the potential benefits of EMIS for decision-making and institutional effectiveness may remain unrealized. This finding suggests that successful EMIS implementation requires parallel investment in change management strategies, including continuous training, participatory system design, sustainability-oriented higher education policy, and clear communication of system benefits (Mader et al., 2013). By actively shaping positive user perceptions, institutions can enhance acceptance, sustained use, and the overall impact of EMIS on educational management outcomes. Moreover, the longitudinal study by Ward et al. (2005) emphasizes that attitudes toward digital technologies can change over time and should therefore be managed beyond the initial implementation phase of a system. Ultimately, the integration of digital technologies such as EMIS in educational settings requires ongoing support, attention to critical factors, and a cultural shift toward embracing digital tools (Mwangi–Ng'ayo et al., 2023).

Another finding revealed that CTD was positively associated with EMIS, supporting Hypothesis 2. This aligns with previous research suggesting that creative approaches to integrating digital tools foster innovation in educational data management, leading to more adaptive and responsive systems (Di Vaio et al., 2021; Lee-Partridge et al., 2000; Massaro et al., 2012; Seidel et al., 2010). Widiyatmoko et al. (2024) argued that the development of web-based systems can significantly improve data management efficiency within educational processes, showing how creativity can lead to solutions that enhance operational effectiveness. In addition, Kuleshova et al. (2021) emphasized the critical role of creativity in digital education models. They argued that the creative component of digital learning encourages students to tackle interdisciplinary problems, thereby increasing their engagement and motivation. This holistic approach underscores the importance of fostering creative thinking in educational settings, allowing more innovative EMIS applications that are tailored to the specific needs of educational institutions. From an implementation perspective, this implies that EMIS success depends not only on system functionality but also on whether institutions intentionally create conditions that encourage experimentation, flexibility, and creative problem-solving in digital practices. Without organizational structures that allow users to adapt EMIS features, propose innovations, and integrate the system into local workflows, creative potential may remain underutilized. Therefore, institutions should move beyond standardized EMIS deployment models and adopt flexible governance approaches that support user-driven innovation and contextual customization. Furthermore, the work of Del-Valle-Rojas et al. (2023) provides compelling evidence that educational leadership plays an essential role in promoting creativity among teachers. Their findings suggest that when teachers feel supported in their creative efforts to implement digital solutions, they are more likely to enhance the usability and effectiveness of EMIS, ultimately improving teaching and learning outcomes. This points to the need for institutional frameworks that empower and incentivize creative approaches in educational management. The evidence positions creativity as a fundamental aspect of successful educational information management and demonstrates that fostering an environment where new ideas can flourish is essential for the sustained success of EMIS.

Furthermore, this study found that ATD positively predicted CTD, supporting Hypothesis 3. This finding is consistent with previous research (Panori et al., 2021; Van Deursen et al., 2021). According to Crittenden et al. (2019), individuals who embrace digitalization are more likely to experiment with novel tools and approaches, thereby fostering creative digital solutions. Similarly, Bruno and Canina (2019) observed that a constructive attitude toward technology encourages exploration, adaptability, and problem-solving, which are key drivers of digital creativity. Tuan (2022) further highlights that individuals who maintain an optimistic outlook on technology are more inclined to explore new digital tools and approaches, facilitating the development of creative and effective solutions in educational contexts. This relationship is crucial because it suggests that when educators feel empowered and positive about digitalization, their creativity flourishes, resulting in innovative instructional strategies that better meet learners' needs (Cahyono et al., 2025; Suherman & Vidákovich, 2024b). These insights suggest that cultivating a positive attitude toward digitalization is essential not only for effective EMIS use but also for nurturing creativity in digital processes, thereby amplifying the benefits of technology integration in education. From a practical standpoint, this finding implies that efforts to enhance digital creativity should begin by strengthening users' attitudes toward digitalization through targeted training, mentoring, and supportive digital cultures. Professional development initiatives that emphasize confidence-building, experimentation, and reflective digital practice may be particularly effective in translating positive attitudes into creative outcomes. Without such attitudinal foundations, investments in advanced EMIS technologies may fail to generate meaningful innovation because users may lack the motivation or confidence to explore their full potential.

Interestingly, the study also found that CTD positively mediated the association between ATD and EMIS, supporting Hypothesis 4. This result aligns with the perspective that while a positive attitude toward digitalization provides the motivational foundation for technology adoption, the creative application of digital tools transforms such attitudes into tangible improvements in system performance (Janse Van Rensburg et al., 2022; Safavi & Ghazinoory, 2024; Shao et al., 2022). Prior studies, such as Skrbinjek et al. (2024), have shown that creativity serves as a critical mechanism through which digital attitudes are translated into innovative and efficient practices in educational management. Moreover, in the context of educational management, creative digitalization empowers stakeholders to design new workflows, develop data visualization dashboards, integrate interoperable platforms, and streamline decision-making processes (Martínez-Peláez et al., 2024). By allowing stakeholders to design customized solutions, adapt EMIS functionalities, and address context-specific challenges, CTD enhances the value of ATD in driving successful EMIS implementation. This mediating role underscores the importance of not only fostering positive digital attitudes but also equipping users with the skills and opportunities to engage creatively with digital systems. From an institutional perspective, this finding suggests that EMIS implementation strategies should move beyond awareness-building or attitude change alone and place greater emphasis on enabling creative digital practices. Training programs should be designed not merely to promote system acceptance but also to develop users' capacity to experiment with, customize, and innovatively apply EMIS functionalities to their specific organizational contexts. At the policy level, flexible governance structures and institutional support for experimentation can further strengthen the translation of positive digital attitudes into effective and sustainable EMIS outcomes through participatory and communicative processes that involve school staff in shaping and improving system implementation (Hillen, 2020).

In addition to individual attitudes and creativity, EMIS adoption may also be influenced by institutional and policy-level factors. For example, organizational support, leadership commitment, and the availability of resources and training programs can significantly shape the effectiveness of EMIS implementation, as well as user motivation and engagement (Donmez-Turan, 2020; Hidayatullah et al., 2024). Policies that encourage innovation, provide incentives for creative engagement, and ensure equitable access to digital tools can further enhance the positive effects of ATD and CTD on system outcomes. Recognizing these contextual factors highlights that while individual attitudes and digital creativity are critical, their full potential is realized when they are supported by conducive institutional frameworks and policies.

Despite its valuable contributions, this study has several limitations that should be acknowledged. First, the research relied on self-reported data, which may be subject to response bias or social desirability effects, potentially influencing the precision of the attitudes, creativity, and EMIS use reported by the participants. Second, the study design was cross-sectional, limiting the ability to establish causal relationships between ATD, CTD, and EMIS effectiveness. Third, the sample was drawn from a specific educational context, which may restrict the generalizability of the findings to other regions or educational systems with different technological infrastructures and cultural attitudes toward digitalization. In addition, the study focused primarily on individual-level factors (attitude and creativity) and did not account for institutional, technical, or policy-related variables that might also influence EMIS implementation and performance.

Future research should address these limitations by employing longitudinal designs to explore how ATD and CTD evolve over time and how these changes influence EMIS adoption and impact. Expanding the scope of research to include diverse educational settings, countries, and institutional contexts would improve the generalizability of the findings. Moreover, integrating multi-source data, such as system usage logs, performance metrics, and qualitative interviews, could provide a more comprehensive understanding of how attitudes and creativity translate into actual EMIS usage and innovation. Future studies should also examine the role of organizational culture, leadership support, and infrastructure readiness in strengthening the link between ATD, CTD, and EMIS outcomes. By incorporating these broader contextual and structural factors, future research can develop a more holistic framework to optimize EMIS implementation in education.

CONCLUSION

In conclusion, the findings of this study highlight the critical interplay between ATD, CTD, and EMIS. The evidence shows that ATD has a direct positive association with EMIS performance and also significantly predicts CTD, which in turn positively impacts EMIS. In addition, the mediating effect of CTD between ATD and EMIS underscores that while positive attitudes form the foundation for technology adoption, the creative use of digital tools transforms these attitudes into meaningful innovations that improve performance. These findings align with previous literature emphasizing that user perceptions and creative capacities are key drivers of successful technology implementation in educational settings. Therefore, both attitudinal and creative dimensions must be strategically cultivated to maximize the benefits of EMIS and ensure its adaptability to changing educational demands.

The implications of this research extend to policymakers, school leaders, and educational technology developers. First, institutions should invest in continuous professional development programs that not only enhance digital literacy but also nurture creative problem-solving skills among educators and administrators, so that EMIS can be implemented more efficiently in daily institutional practices. Second, leadership must foster an organizational culture that values innovation and provides incentives for creative digital practices, allowing staff to tailor EMIS functionalities to their unique institutional contexts and thereby improve the efficiency of administrative and academic processes. Third, policymakers should consider integrating creativity-focused digital competency frameworks into teacher training curricula to ensure that future educators are equipped to leverage EMIS innovation for more efficient and effective educational management. By addressing both attitudinal readiness and the creative application of digital tools, stakeholders can ensure that EMIS functions not only as an administrative instrument but also as a dynamic driver of educational improvement, innovation, and efficiency.

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EVALUATING THE IMPACT OF AI-SUPPORTED INQUIRY-BASED LEARNING ON STUDENTS' CREATIVE MATHEMATICAL PERFORMANCE, CRITICAL PROBLEM-SOLVING SKILLS, AND ATTITUDES TOWARD MATHEMATICS

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ABSTRACT

Mathematics education increasingly requires teaching approaches that strengthen students' creativity, problem-solving skills, and positive attitudes toward learning. However, limited evidence exists on the effectiveness of AI-supported inquiry-based learning in developing multiple dimensions of mathematical competence among secondary school students. This study examined the impact of AI-supported inquiry-based learning on creative mathematical performance, critical problem-solving skills, and attitudes toward mathematics. Using a quasi-experimental design, students with a mean age of 12.79 years (*SD* = 0.68) were assigned either to an experimental group receiving AI-supported inquiry-based learning or to a control group receiving conventional instruction. Data were collected through validated tests and questionnaires. The results showed that AI-supported inquiry-based learning significantly improved students' creative mathematical performance and attitudes toward mathematics compared with traditional instruction, but it did not produce a statistically significant improvement in critical problem-solving skills. Multivariate analysis confirmed a significant overall group effect, while correlation analysis showed positive relationships among all variables in both groups. Overall, the findings suggest that AI-supported inquiry-based learning mainly supports creativity and affective development, while its effect on problem-solving skills remains limited. It may also improve instructional efficiency through guided exploration, adaptive feedback, and reduced cognitive load.

KEYWORDS

AI-assisted learning, attitude toward mathematics, creative mathematical performance, critical problem-solving skills, inquiry-based learning

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Highlights

- *AI-IBL improved students' creative mathematical performance.*
- *AI-supported inquiry learning strengthened attitudes toward mathematics.*
- *Strong correlations emerged among creativity, problem-solving, and attitude.*
- *AI-IBL promoted active engagement and higher-order mathematical thinking.*

INTRODUCTION

Mathematics education has undergone a fundamental transformation as educators increasingly recognise that memorisation and direct instruction alone are insufficient for developing the competencies students need today. Inquiry-based learning (IBL) enables students to develop critical thinking, creative thinking, and deep mathematical understanding through active problem-solving activities (Niyonizera, 2023). At the same time, artificial intelligence (AI) is increasingly being used in education to create individualised learning experiences that adapt to students' needs and make learning more interactive (Haq, 2025; Khan and Begum, 2025).

Combining AI technology with inquiry-based learning offers considerable potential for educational development. AI tools allow students to explore mathematics dynamically, provide immediate feedback, and support inquiry processes that help learners address complex mathematical problems (Asghr et al., 2025). Although research indicates that AI-based interventions can improve critical thinking and problem-solving abilities (Asghr et al., 2025), less is known about how AI-supported inquiry-based learning affects students' mathematical creativity and attitudes toward mathematics in quasi-experimental studies. Research shows that inquiry-based learning models can contribute to the development of students' creative and critical thinking abilities (Suherman et al., 2025), while AI-based educational tools show potential for enhancing complex mathematical thinking (Kim et al., 2025). However, limited empirical evidence has examined how AI-supported inquiry-based learning influences students' creative mathematical performance, critical problem-solving skills, and attitudes toward mathematics compared with traditional instructional approaches (Khan and Begum, 2025). This issue is particularly relevant in Indonesia, where strengthening students' higher-order thinking skills remains a key educational priority in response to persistent challenges in mathematics achievement and creativity development. Indonesia is also representative of many developing education systems that are undergoing digital transformation while continuing to struggle with fostering creativity and problem-solving competence in mathematics learning. Therefore, examining instructional innovations such as AI-supported inquiry-based learning in this context has both local significance and broader relevance for similar educational settings globally.

Evidence from the Programme for International Student Assessment (PISA) highlights these challenges. In PISA (2024), Indonesia was among the countries with the lowest performance in creative thinking, with a substantial proportion of students failing to reach baseline proficiency levels (59.0%). Similar patterns of underperformance were also observed across several other participating countries, particularly in developing and emerging education systems. This indicates that low levels of creative thinking in mathematics and problem-solving are not unique to Indonesia, but reflect a broader global issue. Figure 1 illustrates the distribution of students below baseline proficiency in creative thinking among low-performing participating countries.

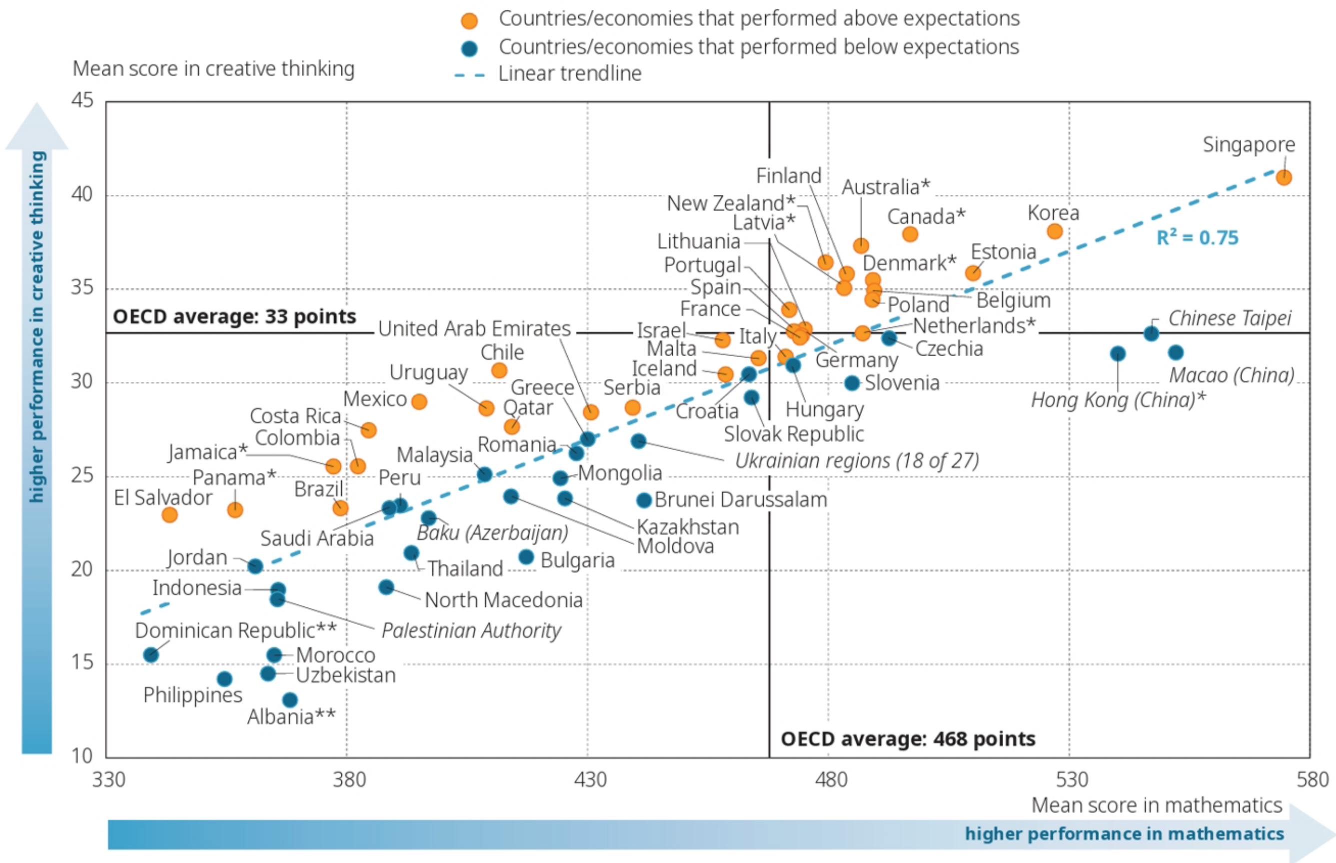

Figure 1: Mean scores in creative thinking and mathematics performance across countries participating in PISA 2024 (Source: OECD, (2024))

These developments reflect the growing integration of inquiry-based pedagogy and artificial intelligence in mathematics education, offering new opportunities to enhance how students learn and engage with mathematical ideas. At the same time, stronger empirical evidence is needed on how this integration works in practice, particularly in relation to students' creative mathematical performance, critical problem-solving skills, and attitudes toward mathematics compared with traditional instruction. This gap is especially relevant in education systems that are undergoing rapid digital transformation while continuing to face challenges in developing higher-order mathematical thinking. Therefore, this study systematically examined the effects of AI-supported inquiry-based learning on students' creative mathematical performance, critical problem-solving skills, and attitudes toward mathematics using a quasi-experimental design. The study addressed the following three research questions:

1. Does AI-supported inquiry-based learning enhance students' creative mathematical performance compared to traditional instruction?
2. What is the impact of AI-supported inquiry-based learning on students' critical problem-solving skills?
3. How does participation in AI-supported inquiry-based learning affect students' attitudes toward mathematics?

LITERATURE REVIEW

Foundation of Inquiry-Based Learning

Inquiry-based learning (IBL) is grounded in constructivist educational theories, which posit that learners actively construct knowledge rather than passively receive information. Constructivist principles suggest that knowledge develops through meaningful experiences that encourage exploration, questioning, and discovery. This perspective shifts the teacher's role from that of a transmitter of facts to a facilitator who guides students through active learning processes. In this regard, IBL emphasises student-centred discovery, enabling learners to explore complex mathematical problems and develop meaningful understanding through firsthand investigation rather than rote memorisation or procedural repetition (Niyonizera Daniel, 2023).

The effectiveness of IBL depends on adequate scaffolding and guided inquiry structures, which ensure that students are supported while also being challenged to engage deeply with the material. Scaffolding, a concept introduced by Vygotsky and later developed in educational psychology, refers to temporary support provided to learners to help them attain higher levels of understanding and skill mastery. In inquiry-based settings, such support may include probing questions, problem-solving frameworks, and conceptual clarification, all of which are gradually reduced as learners become more proficient (Anugrah et al., 2025). This type of scaffolding can build students' confidence and autonomy, both of which are essential for sustaining engagement and advancing cognitive skills.

The implementation of IBL in mathematics education has been shown to provide significant benefits, including the development of creativity, critical thinking, and problem-solving capabilities. Students who participate in inquiry-oriented mathematics instruction demonstrate stronger abilities to generate innovative solutions, analyse problems from multiple perspectives, and apply logical reasoning in novel contexts. Empirical research linking inquiry-based methodologies with improvements in scientific and mathematical thinking supports the value of this approach in complex domains such as mathematics (Engeln et al., 2013; Wale & Bishaw, 2020). By promoting exploration and reflection, IBL fosters curiosity and cognitive flexibility that align with the demands of 21st-century learning.

Despite these advantages, implementing IBL may also present several instructional challenges. Inquiry-oriented learning activities often require more classroom time and more careful instructional planning than conventional approaches (Kolbe et al., 2020). In addition, some students, particularly those with limited prior knowledge, may initially experience difficulty when engaging in open-ended inquiry tasks. Studies grounded in cognitive load theory suggest that inquiry activities are most effective when accompanied by appropriate scaffolding and structured guidance from teachers (Kalyuga & Singh, 2016). Therefore, the success of IBL depends not only on student exploration but also on the quality of instructional support provided throughout the learning process.

The importance of artificial intelligence in mathematics education

The integration of AI into teaching draws on sociocultural and constructivist theories, which suggest that meaningful learning is best achieved when instruction is tailored to learners' needs and actively involves students in constructing understanding. The personalisation capacity of AI in education enables content and pacing to be adapted to student responses, making it possible to provide differentiated instruction that is difficult to achieve in traditional classroom settings.

The integration of artificial intelligence into educational scaffolding can enhance learning by providing adaptive, personalised interactions that respond to individual learners' needs in real time. AI-driven systems can analyse student responses, detect error patterns, and tailor feedback to optimise learning pathways. This adaptive capability improves personalisation by adjusting difficulty levels, offering hints, or providing exploratory prompts based on each learner's performance and engagement, thereby supporting a more efficient and individualised learning experience (Mohsin Ayaz Khan, 2025).

In addition to basic adaptation, AI can serve as cognitive and metacognitive scaffolding, supporting learners not only in mastering content but also in regulating their own learning processes. This approach can promote metacognitive awareness by encouraging students to reflect on their problem-solving strategies, plan their approaches, and evaluate outcomes critically. Such cognitive support may enhance self-regulation and motivation, empowering learners to take ownership of their learning and persist in challenging tasks (Asghr et al., 2025). Furthermore, AI's capacity to monitor learning progress and provide formative feedback is closely aligned with pedagogical theories that advocate ongoing assessment and personalised instruction (Minjung Kim, 2025).

The intersection of AI technology and educational pedagogy has given rise to an emerging hybrid model in which AI tools complement teacher-led inquiry by addressing gaps in real-time support and increasing the scalability of individualised learning. This synergy represents a significant advancement in personalised inquiry support, as AI can enhance the teacher's capacity to scaffold diverse learning trajectories, particularly in complex, open-ended mathematical activities. Integrating AI with pedagogical frameworks may therefore strengthen the effectiveness of inquiry-based learning in achieving diverse and meaningful educational outcomes.

Although AI technologies offer considerable potential for personalised learning and adaptive feedback, several challenges should also be considered in educational implementation (Strielkowski et al., 2025). AI-generated responses may occasionally provide oversimplified explanations or inaccurate reasoning in complex mathematical contexts (Sirnoorkar et al., 2024). Moreover, excessive reliance on AI assistance could reduce opportunities for students to develop deep reasoning and reflective thinking skills independently (Zhai et al., 2024). Nevertheless, recent studies emphasise that these limitations can be minimised when AI is used as a supportive learning tool under appropriate teacher supervision and within an inquiry-based instructional design, rather than as a replacement for active student thinking and classroom interaction (Yeh, 2025).

The role of inquiry in supporting creativity and critical thinking

IBL can be regarded as a dynamic pedagogical approach that fosters creativity and critical thinking by allowing students to engage actively in the learning process. In IBL environments, students are encouraged to pose questions, explore, and investigate in order to construct knowledge, thereby developing inquiry and problem-solving skills (Smith et al., 2022). Research indicates that IBL enhances critical thinking by training students in essential cognitive skills such as problem formulation, data collection, evaluation, and information synthesis (Kadir & Satriawati, 2017; Wale & Bishaw, 2020). This enhancement is especially evident when guided inquiry-based modules are used, as they have been shown to improve students' capacity to think critically and apply learning in context (Alqarni, 2025; Wale & Bishaw, 2020). Moreover, empirical studies demonstrate that IBL can deepen students' understanding of scientific processes, stimulating critical thinking and an innovative mindset that are essential for solving complex, real-world problems (Dagys, 2017; Syahgiah et al., 2023).

Furthermore, IBL can substantially strengthen students' creativity through its emphasis on exploration and self-directed learning. This pedagogical approach encourages students to move beyond conventional frameworks and continually refine their ideas and methods in response to empirical findings and learning experiences (Sam, 2024). For instance, the implementation of IBL in science education has shown that students who engage in inquiry-oriented tasks develop not only scientific knowledge but also a creative disposition that enables them to imagine new possibilities and solutions (Umbara et al., 2017; Wale & Bishaw, 2020). This instructional approach is also consistent with constructivist educational theories, which propose that knowledge is constructed through experience and interaction, thereby empowering students to formulate original ideas and creatively address challenges (Baldock & Murphrey, 2020; Thoron & Burleson, 2014). Overall, inquiry-based learning creates an academic environment that supports the development of creativity and critical thinking skills, preparing students for both academic tasks and real-world applications.

AI-enabled technologies and attitudes toward mathematics

The implementation of AI-enabled technologies in mathematics education can substantially influence students' attitudes toward the subject. As educators increasingly adopt AI-supported personalised learning methods, students have more opportunities to receive individualised support, which can enhance their performance and foster more positive attitudes toward mathematics (Opesemowo & Ndlovu, 2024; Orhani, 2021). AI technologies can diagnose individual learning challenges and tailor instructional strategies accordingly, leading to improved engagement and comprehension in mathematics (Opesemowo & Ndlovu, 2024; Orhani, 2021). This tailored approach addresses students' distinct learning needs, potentially reducing anxiety and enhancing self-efficacy in mathematics (Wang, 2025). Studies have also indicated that integrating AI into inquiry-based creative learning environments may improve academic performance, suggesting significant potential for transforming students' perceptions of the subject (Yeh, 2025). Furthermore, existing research indicates a relationship between positive attitudes toward AI and mathematics, suggesting that students' perceptions of AI technologies can significantly influence their feelings about mathematics learning (Bation & Pudan, 2024; Hussain, 2020). For instance, the use of AI-based applications can enhance the effectiveness of educational methods and support the achievement of learning objectives, thereby creating an environment that fosters positive attitudes toward mathematics (Aykan, 2024). The impact of these technologies extends beyond academic performance by cultivating a mindset that values iterative problem-solving and critical thinking (Çela et al., 2024). These skills are essential in mathematics. AI-enabled technologies therefore influence not only how mathematics is taught, but also how students engage with the subject, encouraging deeper involvement with mathematical concepts and applications in their academic lives (Hwang & Son, 2021; Shakya & Maharjan, 2023).

METHODS

Participants

The research sample consisted of 120 Grade 8 students (79 females and 41 males; mean age = 12.79 years, SD = 0.68) drawn from two public middle schools in Bandar Lampung City, Indonesia. The two schools were selected because they had comparable socioeconomic and educational contexts, as both were urban public schools with similar institutional characteristics and resource availability. However, no individual-level matching procedure was conducted because of the intact-class quasi-experimental design and practical constraints in school settings. Instead, class equivalence was approached at the school level by selecting schools with broadly similar academic and contextual profiles (Suherman et al., 2025). One intact Grade 8 class from each school participated in the study (n = 60 per group). The experimental group receiving AI-supported IBL consisted of 41 females and 19 males, while the control group receiving traditional instruction included 38 females and 22 males. Before data collection, institutional and school permissions were secured, and informed consent was obtained from all participants.

Design

A pretest–posttest non-equivalent groups design was used. The experimental group engaged in mathematics lessons centred on inquiry-based activities and supported by an AI tool (ChatGPT), which provided adaptive feedback, hints, and scaffolding during problem-solving. The control group received teacher-led lessons covering the same topics and problem sets, but without inquiry tasks or AI support (Chaleelpliam et al., 2023). Examples of the experimental activities are presented in Table 1.

Activity Topic	Curricular Focus	AI & Inquiry Themes	Specific AI-IBL Activities
Introduction to Geometry	Understanding basic geometry concepts; distinction between plane and solid figures	Inquiry-based learning: observation and classification	Group discussion: identify geometric shapes in daily life Brainstorming activity: classify classroom objects into plane vs. solid figures
Plane Figures: Square & Rectangle	Properties of squares and rectangles; perimeter and area	AI-assisted visualization: interactive geometric tools	Teacher demonstration with visual aids Individual practice with AI geometry apps to calculate perimeter and area
Plane Figures: Parallelogram, Rhombus, Trapezoid	Properties, perimeter, and area calculation	Inquiry and AI: exploring properties of less common shapes	Group discussion on common mistakes Worksheet exercises using AI-assisted drawing tools for shapes
Introduction to Triangles & Types	Classification of triangles by sides and angles	Inquiry: hands-on exploration	Hands-on activity: creating triangles with paper/rulers Visual examples to classify triangles
Properties of Triangles	Sum of angles, relationships between sides and angles	Inquiry: problem-solving	Solve basic angle problems in groups Real-life examples of triangles
Basic Pythagoras Theorem	Applying Pythagoras theorem in right triangles	Inquiry and AI: calculation support	Identify right triangles in images or diagrams Use AI tools to calculate missing sides ($a^2 + b^2 = c^2$)
Triangles in Real Life Applications	Application of triangles in architecture, art, engineering	AI & inquiry: real-world problem identification	Virtual tour / photo analysis of buildings with triangles Project: students diagram triangles in their environment
Review & Assessment	Integration of all concepts: plane figures, triangles, and calculations	Inquiry-based assessment; AI-assisted feedback	Integrative exercises combining perimeter, area, triangle identification, Pythagoras AI tools for instant feedback on calculations

Table 1: AI-IBL Activities (Source: own elaboration)

This study included only Grade 8 students because students at this developmental stage are generally considered capable of engaging in higher-order thinking processes, including abstract reasoning, problem-solving, and creative mathematical thinking. According to Piaget's theory of cognitive development, early adolescents typically begin transitioning into the formal operational stage, which enables more logical and hypothetical reasoning (Piaget, 1976). Previous mathematics education research has also shown that middle school students possess sufficient cognitive readiness to participate in inquiry-based and problem-solving-oriented learning activities that require analytical and creative thinking (Belland et al., 2011; Bicer et al., 2021). At this level, students have usually acquired foundational knowledge of geometry, making them suitable for examining the effects of AI-supported inquiry-based learning on mathematical skills. Limiting participants to a single grade also helped ensure relatively similar cognitive and educational backgrounds, thereby reducing variability associated with developmental and curricular differences.

The assignment of classes to the experimental and control conditions was conducted using a lottery-based procedure, in which the first class drawn was assigned to the experimental group and the second to the control group. However, this procedure was implemented within practical constraints imposed by school scheduling. Because it was not feasible to create new classes or reorganise existing timetables, the selection of participating classes was coordinated with school administrators to ensure compatibility with academic schedules and teacher availability. To strengthen the internal validity of the study, efforts were made to ensure that the selected classes were comparable in terms of prior academic exposure, curriculum coverage, and learning experiences before the intervention.

In the experimental class, instruction was organised around small-group activities, with students grouped according to age, interests, developmental readiness, and skill levels. These groups engaged in collaborative AI-IBL activities, such as exploring two- and three-dimensional shapes, calculating areas and perimeters, and constructing and analysing triangles. Research indicates that group-based, inquiry-oriented instruction is often more effective than traditional one-on-one teaching approaches. In contrast, the control class followed the standard curriculum, which relied on teacher-led lectures, individual exercises, and minimal hands-on problem-solving, thereby providing a baseline for comparison. The study's experimental design is shown in Figure 2.

Sessions began at around 8:30 a.m. and lasted 60–90 minutes, typically starting with a brief physical activity to help students release energy and focus on learning. After completing the nine-week AI-IBL geometry programme, students' creative and critical thinking skills were assessed, and outcomes from the experimental and control groups were compared.

Finally, after the intervention, students completed two types of post-assessment measures. First, a post-test was administered to evaluate students' creative mathematical performance and critical problem-solving skills, with a duration of approximately 45–60 minutes. Second, a follow-up questionnaire was administered to assess students' attitudes toward mathematics. The questionnaire was completed individually in a quiet setting and took approximately 5–10 minutes per student.

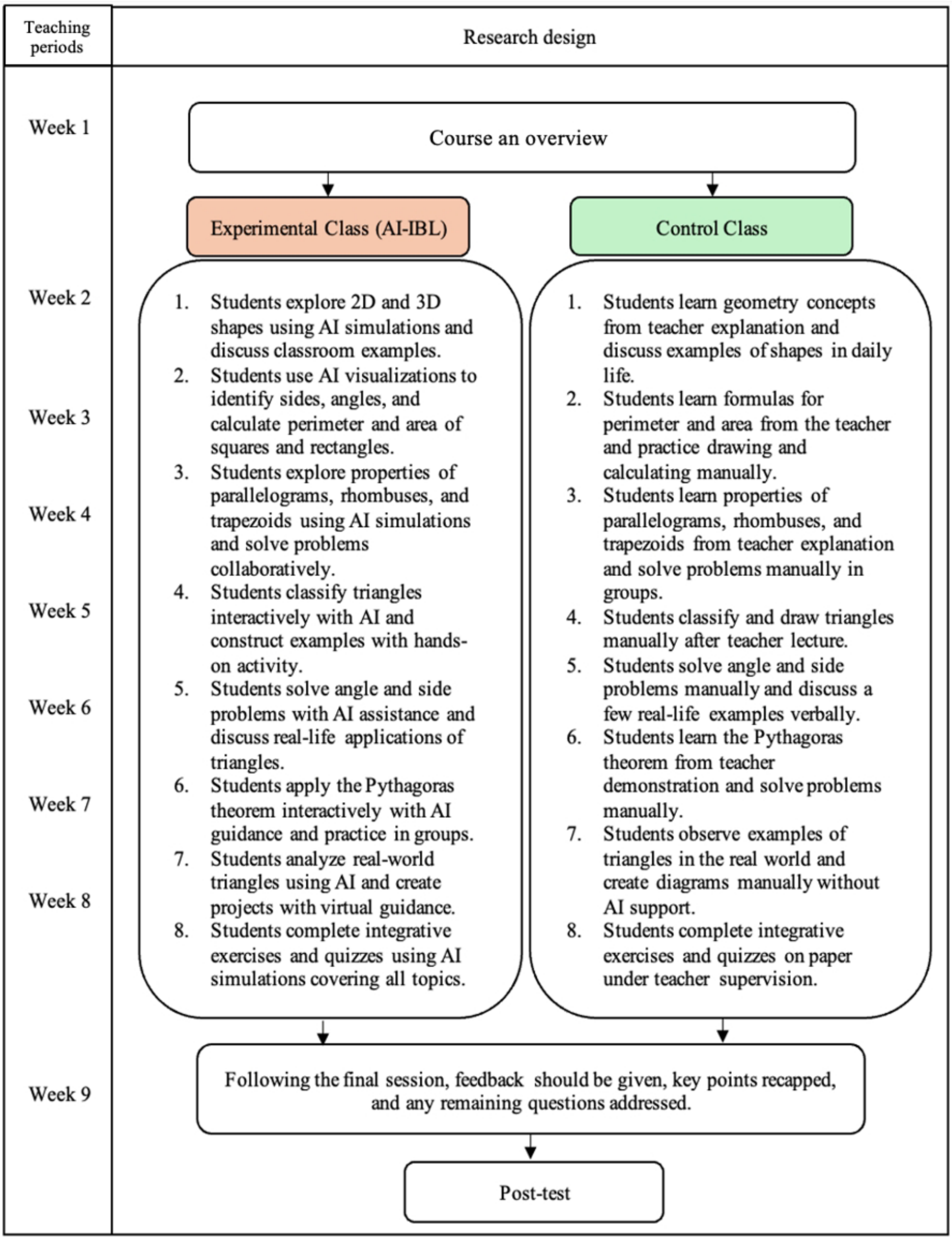

Figure 2: Research procedure (Source: modified from Suherman et al. (2025))

Instrument

The instruments used in this study consisted of a questionnaire and two separate essay-based tests. The questionnaire assessed students' attitudes toward mathematics. The first essay test measured creative mathematical performance (CMP) and consisted of five open-ended items. The second essay test measured critical problem-solving (CPS) and consisted of four open-ended items. Both tests required students to solve non-routine mathematical problems and were adapted from Suherman and Vidákovich (2025). An example of the essay test items is presented in Figure 3. Students' responses were scored using a five-point analytic rubric (1–5) to assess both CMP and CPS. A score of 1 indicated very limited or incorrect responses with no valid mathematical reasoning, while a score of 2 reflected minimal understanding with largely incorrect or incomplete solutions. A score of 3 represented partially correct responses with some appropriate steps but noticeable errors in reasoning or computation. A score of 4 indicated mostly correct and logically structured solutions with minor errors, whereas a score of 5 represented fully correct, well-reasoned, and complete solutions demonstrating strong mathematical understanding. For CMP, this included originality of strategies, while for CPS it reflected strong logical justification and problem-solving accuracy.

The triangle is designed by Tapis Lampung ornament with *Jung Sarat* motif. The triangle is a right triangle with legs 8 and 6. The vertices are at the points A(0,0), B(0,6), and C(0,8). The red line segment is perpendicular to hypotenuse. Find the length of the red line segment.

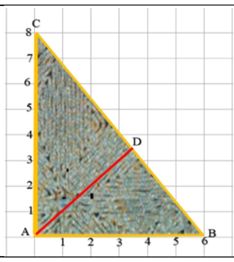

Figure 3: An example of a creative and critical thinking test (Source: adapted from Suherman and Vidákovich (2025))

The Attitude toward Mathematics questionnaire was adapted from Suherman and Vidákovich (2022) and included five statements, each with five response options. Scores were assigned using a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Sample items included statements such as "I am really good at math" and "I feel confident in my abilities to solve mathematics problems."

In this study, the validity and reliability of the instruments were evaluated. The critical thinking test initially included five items; however, one item had a factor loading below 0.4 and was therefore removed, leaving four valid items. The creative thinking test consisted of five items, and the Attitude toward Mathematics questionnaire also contained five items. A summary of the instruments' validity and reliability is presented in Table 2.

Items	Loading factors	Cronbach's alpha (standardized)	Composite reliability (rho_c)	Average variance extracted (AVE)
Creative mathematical performance (CMP)		0.921	0.924	0.703
CMP1	0.700			
CMP2	0.798			
CMP3	0.880			
CMP4	0.870			
CMP5	0.925			
Critical problem-solving (CPS)		0.710	0.728	0.401
CPS1	0.651			
CPS2	0.829			
CPS3	0.524			
CPS4	0.469			
Attitude toward Mathematics (ATM)		0.903	0.902	0.651
ATM1	0.767			
ATM2	0.808			
ATM3	0.856			
ATM4	0.822			
ATM5	0.780			

Table 2: Psychometric evaluation of the instruments (Source: own elaboration)

Data analysis

The data were analysed using both descriptive statistics (means and standard deviations) and inferential statistics to compare groups and report effect sizes, primarily using SPSS 31. SPSS was used to conduct correlation analyses, independent samples t-tests, and MANOVAs to examine differences between the experimental and control groups across multiple dependent variables. SmartPLS 4 was used to assess the psychometric properties of the instruments, while R software was used to generate visualisations illustrating students' performance across all variables in both groups.

RESULTS

Table 3 presents the descriptive statistics and correlation analysis among CMP, CPS, and ATM for both groups. The experimental group showed slightly higher mean scores across all variables (CMP = 3.63, CPS = 3.36, ATM = 3.56) than the control group (CMP = 3.22, CPS = 3.17, ATM = 3.14), with comparable levels of dispersion, as indicated by standard deviations ranging from 0.77 to 0.95. Skewness and kurtosis values further confirmed that the data approximated a normal distribution in both groups.

The correlation analysis revealed strong and statistically significant positive relationships among all variables in both groups. However, the control group consistently demonstrated slightly stronger interrelationships among CMP, CPS, and ATM (r = 0.720 to 0.896) than the experimental group (r = 0.688 to 0.892). This indicates that the associations among cognitive and affective variables were more tightly connected under traditional learning conditions, whereas the AI-IBL intervention resulted in slightly weaker interdependencies among the constructs.

Group	Variable	M	SD	Skewness	Kurtosis	CMP	CPS	ATM
Experimental	CMP	3.63	0.89	-0.32	-0.23	-		
	CPS	3.36	0.92	-0.46	-0.33	0.718**	-	
	ATM	3.56	0.77	-0.51	-0.72	0.892**	0.688**	-
Control	CMP	3.22	0.95	-0.16	-0.23	-		
	CPS	3.17	0.77	0.06	-0.33	0.761**	-	
	ATM	3.14	0.93	0.06	-0.72	0.896**	0.720**	-

*Note: **. Correlation is significant at the 0.01 level (2-tailed).*

Table 3: Summary of descriptive statistics and correlations among groups (Source: own elaboration)

Regarding data normality, following Kline (2015), skewness values within ±3 and kurtosis values within ±10 indicate acceptable normal distribution. In this study, skewness values ranged from -0.51 to 0.06 across both experimental and control groups, while kurtosis values ranged from -0.72 to -0.23. These results suggest that all variables (CMP, CPS, and ATM) demonstrated acceptable levels of normality, indicating that the data distributions did not substantially deviate from normality assumptions.

Homogeneity of variance was examined using Levene's test. The results indicated that the assumption of equal variances was met for all variables, including CMP (F = 0.000, p = 0.986), CPS (F = 1.101, p = 0.296), and ATM (F = 1.714, p = 0.193). Because all p-values exceeded the 0.05 threshold, the homogeneity assumption was satisfied, supporting the use of independent samples t-tests with equal variances assumed.

Multicollinearity was examined using Pearson correlation coefficients among the dependent variables. The results indicated strong positive relationships between CMP, CPS, and ATM, with correlation values ranging from r = 0.695 to r = 0.898. Although the correlation between CMP and ATM was relatively high, it did not exceed the critical threshold of 0.90, suggesting that multicollinearity was not severe and that the variables could be retained for multivariate analysis.

Table 4 presents the results of the multivariate tests examining the effect of group (experimental vs. control) on the combined dependent variables (CMP, CPS, and ATM). The intercept showed a highly significant effect across all dependent variables (Pillai's Trace = 0.948, $F(3,116)$ = 705.94, p < 0.001, η^2 = 0.948), reflecting the overall mean levels of the measures. More importantly, the group effect was statistically significant at the multivariate level (Pillai's Trace = 0.065, $F(3,116)$ = 2.694, p = 0.049, η^2 = 0.065), indicating a significant difference between the experimental and control groups when the dependent variables were considered together. The effect size (η^2 = 0.065) suggests a small-to-moderate practical impact of the intervention. This finding implies that the instructional approach, namely the AI-IBL intervention, influenced students' creative mathematical performance, problem-solving skills, and attitudes toward mathematics collectively, warranting further investigation through follow-up univariate tests for each variable.

Effect	Value	*F*	Hypothesis *df*	Error *df*	*Sig.*	η^2
Intercept						
Pillai's Trace	0.948	705.936	3	116	<0.001	0.948
Wilks' Lambda	0.052	705.936	3	116	<0.001	0.948
Hotelling's Trace	18.257	705.936	3	116	<0.001	0.948
Roy's Largest Root	18.257	705.936	3	116	<0.001	0.948
Group						
Pillai's Trace	0.065	2.694	3	116	0.049	0.065
Wilks' Lambda	0.935	2.694	3	116	0.049	0.065
Hotelling's Trace	0.070	2.694	3	116	0.049	0.065
Roy's Largest Root	0.070	2.694	3	116	0.049	0.065

Table 4: Multivariate test results (Source: own elaboration)

To evaluate the effects of the instructional intervention on students' outcomes, independent samples t-tests were conducted for CMP, CPS, and ATM, as presented in Table 5. The results showed that students in the experimental group achieved significantly higher CMP scores (M = 3.63, SD = 0.90) than those in the control group (M = 3.22, SD = 0.95), $t(117.579) = 2.386$, $p = 0.019$, $d = 0.436$, indicating a moderate effect of the AI-IBL approach on creative mathematical performance. Similarly, students in the experimental group reported significantly higher ATM scores (M = 3.56, SD = 0.77) than the control group (M = 3.14, SD = 0.93), $t(114.257) = 2.702$, $p = 0.008$, $d = 0.493$, suggesting a moderate positive effect of the intervention on attitudes toward mathematics. In contrast, no statistically significant difference was found in CPS between the experimental group (M = 3.36, SD = 0.92) and the control group (M = 3.17, SD = 0.77), $t(114.640) = 1.213$, $p = 0.228$, $d = 0.221$, suggesting that the intervention had a limited effect on critical problem-solving skills. Overall, these findings indicate that the AI-IBL instructional approach was most effective in improving creative mathematical performance and students' attitudes toward mathematics, while its impact on critical problem-solving skills remained relatively small. The distribution of students' performance across variables is illustrated in Figure 4.

Variables	Experimental *M* (*SD*)	Control *M* (*SD*)	*t*	*df*	*p*	Cohen's *d*
CMP	3.63 (0.90)	3.22 (0.95)	2.386	117.579	0.019	0.436
CPS	3.36 (0.92)	3.17 (0.77)	1.213	114.640	0.228	0.221
ATM	3.56 (0.77)	3.14 (0.93)	2.702	114.257	0.008	0.493

Table 5: Summary of the independent sample *t*-test (Source: own elaboration)

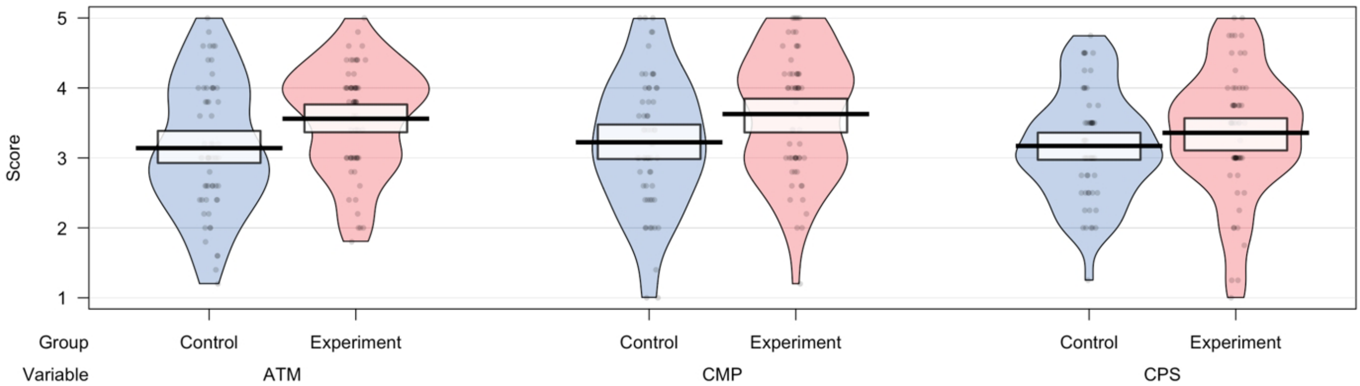

Figure 4: Students' performance among variables (Source: R software output)

DISCUSSION

The results of this study demonstrate that the AI-IBL instructional approach had a positive impact on students' mathematical learning outcomes, particularly attitudes toward mathematics and creative mathematical performance, with the strongest effect observed in the affective domain. Students in the experimental group consistently scored higher than those in the control group across all measured variables. The most pronounced improvement was found in attitudes toward mathematics, indicating that AI-supported inquiry-based learning plays a particularly important role in shaping students' motivation, interest, and emotional engagement in mathematics learning. This was followed by improvements in creative mathematical performance, where students in the experimental group demonstrated greater originality, flexibility, and diversity in solution generation compared with traditional instruction. These findings suggest that AI tools may support divergent thinking processes by scaffolding exploration and prompting multiple solution pathways (Guo et al., 2025; Wei et al., 2025).

The descriptive statistics and correlation analysis showed that CMP, CPS, and ATM were strongly interrelated in both groups. However, slightly stronger interrelationships were observed in the control group than in the experimental group, suggesting that in traditional learning environments, cognitive and affective dimensions tend to be more tightly coupled. In contrast, the AI-IBL condition appeared to promote a more differentiated pattern of relationships among constructs, indicating a possible shift toward more independent development of cognitive and affective domains. This pattern aligns with previous research indicating that inquiry-based learning environments can simultaneously support creativity, problem-solving, and positive attitudes in mathematics education (Bhardwaj et al., 2025; Conradty & Bogner, 2019; Engeln et al., 2013; Huang, 2022).

In contrast, no statistically significant improvement was found in critical problem-solving skills, indicating that the intervention did not produce a measurable effect on this domain. Although students in the experimental group showed slightly higher mean performance, the difference was not sufficient to indicate a meaningful impact. This suggests that, while AI-supported inquiry-based learning may facilitate exploration and idea generation, the development of structured and evaluative problem-solving skills likely requires more sustained instructional scaffolding, explicit metacognitive guidance, and longer-term practice beyond a short-term intervention (Hidayatullah et al., 2024; Lai, 2025).

At the multivariate level, the group effect was significant, indicating that the intervention influenced students collectively across the three dependent variables. Consistent with the univariate results, this finding suggests that the instructional approach primarily affected affective and creative dimensions, while contributing less to structured problem-solving performance. Although the overall effect size was modest, the result confirms that instructional models integrating AI and inquiry-based strategies can produce measurable changes in students' learning outcomes. This aligns with prior studies showing that digital and interactive pedagogical tools can enhance engagement and cognitive development in mathematics education (Cirneanu & Moldoveanu, 2024; Engelbrecht & Borba, 2024).

The findings further suggest that AI-supported inquiry-based learning can foster students' creative mathematical performance and positive attitudes toward mathematics by promoting active exploration, idea generation, and interactive learning experiences. Inquiry-oriented environments supported by generative AI encourage students to engage in open-ended reasoning (Li et al., 2025), receive immediate feedback (Dong et al., 2026), and explore multiple solution pathways (Lee & So, 2025), which may strengthen mathematical creativity and learning engagement. Recent studies have similarly reported that AI-assisted mathematics learning environments contribute positively to students' creativity, motivation, and attitudes (Akosah, 2025; B. Liu et al., 2026; J. Liu et al., 2025) by facilitating adaptive support and reflective learning processes. However, the limited improvement in critical problem-solving skills indicates that higher-order reasoning development requires more sustained scaffolding, metacognitive regulation, and deeper conceptual engagement beyond short-term AI integration.

However, the results warrant several caveats. Not all students experienced the intervention in the same way, as some lower-achieving learners reported initial difficulty adapting to self-directed inquiry even with AI support. Teacher facilitation and peer collaboration appeared to play an important moderating role in supporting student engagement. Although this limitation is consistent with findings from other technology-enhanced inquiry-based studies, it highlights the importance of blended instructional designs that combine digital tools with structured teacher guidance (Supriadi et al., 2025). Furthermore, attitudes toward mathematics remain influenced by broader contextual and socio-emotional factors, including classroom climate, teacher beliefs, and school culture (Hidayatullah & Csíkos, 2023, 2025; Suherman & Vidákovich, 2024).

These findings have important practical implications. In the context of increasing digital transformation in education, fostering positive attitudes and creative thinking in mathematics is essential for preparing students to face complex problem-solving demands. The study highlights the value of AI-supported inquiry-based approaches that encourage active participation, collaboration, and exploration while also enhancing instructional efficiency through timely feedback, adaptive scaffolding, and optimised learning processes. Teachers are therefore encouraged to integrate AI-supported inquiry activities within structured instructional design, ensuring a balance between exploratory learning and guided mathematical reasoning.

LIMITATIONS AND FUTURE RESEARCH

Although this study provides evidence supporting the efficacy of AI-supported inquiry-based mathematics instruction, its quasi-experimental design means that residual selection bias may persist because intact classes were used without random assignment or statistical covariate adjustment at baseline. Because the groups were not randomly assigned, causality should be interpreted with caution. In addition, the intervention occurred over one academic term, so longer-term effects and sustainability remain unknown. Future research should examine the scalability of AI-IBL across diverse school settings, grade levels, and demographic backgrounds. Longitudinal studies could further clarify the persistence of the observed gains, and qualitative investigations may help explain the experiences of lower-achieving or differently motivated students. Studies comparing different AI tools or levels of inquiry complexity would also add valuable nuance to the field.

CONCLUSION

This study demonstrates that AI-supported inquiry-based learning contributes positively to students' creative mathematical performance and attitudes toward mathematics compared with traditional instruction. The findings underscore the value of combining technological innovation with inquiry-driven pedagogy in mathematics education, particularly as schools seek to prepare students for the demands of a rapidly evolving, knowledge-based society. Although students exposed to the AI-supported approach tended to show more favorable critical problem-solving outcomes, the evidence suggests that its influence in this area may be less pronounced and warrants further investigation. Educators and policymakers should therefore consider the strategic use of AI to scaffold inquiry learning, enhance learning effectiveness and instructional efficiency, and address issues of equity and differentiation to ensure that all students benefit from these advances. In addition, AI integration may contribute to more efficient learning processes by providing immediate feedback and reducing delays in concept clarification during classroom activities.

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Full research paper

WHAT MAKES ONLINE PROFESSIONAL DEVELOPMENT WORK? UNPACKING QUALITY ATTRIBUTES AND THEIR IMPACT ON TEACHER SATISFACTION AND PROFESSIONAL PRACTICE

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ABSTRACT

Professional development (PD) is widely recognised as a crucial factor in fostering the quality of teachers' professional practice. Today, online PD is often chosen over offline PD because it offers advantages related to cost, time, and location efficiency. However, compared with offline PD, less research has examined the quality of online PD. This study aimed to investigate the quality attributes of online PD and their impacts on teachers' satisfaction and changes in their professional practice. A cross-sectional design and an online questionnaire were used to collect data from 206 economics teachers in Indonesia. Structural equation modelling was conducted using SmartPLS 3.0 to examine the research hypotheses. The results show that three elements--collaboration, cognitive activation, and clarity and structure--contribute to explaining and establishing the quality of online PD. Furthermore, from the teachers' perspectives on satisfaction and changes in professional practice, online PD was effective in enhancing teachers' pedagogical knowledge and teaching practice. Finally, the study shows that the quality attributes of online PD positively affect participants' satisfaction and changes in teachers' professional practice. Theoretical and practical implications are discussed.

KEYWORDS

Online professional development, professional practice, quality attributes, teachers' satisfaction

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Highlights

- *The limited empirical evidence on the quality attributes of online professional development (PD) underscores the need to identify the key elements that determine its effectiveness in enhancing teachers' professional practice.*
- *This study uses the Community of Inquiry (CoI) framework to examine three core attributes of online professional development: collaboration, cognitive activation, and clarity and structure.*
- *Collaboration, cognitive activation, and clarity and structure are significant factors in shaping the quality of online professional development.*
- *The quality of online professional development is positively associated with teachers' satisfaction and meaningful changes in their professional practice.*

INTRODUCTION

Professional development (PD) has been recognised as a pivotal element in enhancing the quality of teachers' professional practice. Empirical studies have demonstrated that PD plays a crucial role in fostering teachers' creativity, improving the quality of teaching practices, equipping teachers with new teaching skills and approaches, and introducing challenging learning activities (Stemhagen, 2011; Kalinowski et al., 2020; Sims et al., 2021; Meyer et al., 2023; Wadaani, 2023). Although PD is positively related to high-quality professional practice, most previous studies have been conducted in offline or face-to-face PD contexts.

Today, online learning platforms have been widely adopted worldwide (Bragg et al., 2021; Rafsanjani et al., 2022; Rafsanjani et al., 2023), alongside a concurrent increase in the availability of online PD courses (Lantz-Andersson et al., 2018; Darling-Hammond and Hyler, 2020; Bragg et al., 2021; Donitsa-Schmidt and Ramot, 2022). However, limited evidence is available on how online PD can improve teachers' professional practice or which attributes of online PD contribute to fostering or changing that practice. To address this gap, the current study investigates the quality attributes of online PD.

The current study used the Community of Inquiry (CoI) framework developed by Garrison, Anderson, and Archer (Garrison et al., 1999; Garrison et al., 2003; Carrillo and Flores, 2020) to investigate the quality attributes of online PD. According to the CoI framework, the quality of online learning can be understood through three attributes: cognitive presence, social presence, and teaching presence. We also used the Kirkpatrick model, a training evaluation model, to examine the effectiveness of online PD. According to this model, the effectiveness of training programmes can be assessed through participants' satisfaction and the resulting changes in professional behaviour (Kirkpatrick and Kirkpatrick, 2006; Savul et al., 2021; Khan et al., 2023).

The current study provides two main contributions. First, whereas most previous studies have focused on the quality attributes of offline PD that contribute to improving teachers' professional practice, this study investigates the quality attributes of online PD. Second, the study examines the effectiveness of online PD by analysing the relationship between online PD quality, teachers' satisfaction, and changes in professional practice. Therefore, this study extends knowledge of online PD in relation to quality attributes, satisfaction, and changes in professional practice.

THEORETICAL FRAMEWORK

Online PD

Empirical studies have shown that professional development is crucial for improving instructional quality and students' learning outcomes. However, offline or face-to-face PD presents several challenges: it can be costly, it may have limited capacity to provide broad access (Hill, 2015; Yoon et al., 2020; Bragg et al., 2021), and many teachers work in remote geographical locations (Peltola et al., 2017). Other studies have shown that low expectations regarding PD quality are one reason why teachers do not participate in formal PD (Richter et al., 2018; Zhang et al., 2020). To address these challenges, online delivery has become an increasingly viable mode for facilitating professional development. Online PD offers broader accessibility for teachers at a lower cost, minimises geographical barriers, and provides greater time flexibility (Compen et al., 2019; Dede et al., 2019; Ansyari et al., 2022).

Online PD is conceptualised as a structured online learning experience or training opportunity delivered through information and communication media to improve teachers' teaching skills and support changes in their professional practice (Bragg et al., 2021; Ansyari et al., 2022). In this sense, online PD gives teachers broader opportunities to continue learning and to improve their teaching skills without attending face-to-face courses or training. It offers several benefits, including flexible access to professional development for teachers with limited time or those in isolated locations (Powell and Bodur, 2019; Meyer et al., 2023), as well as reduced time otherwise spent commuting to offline PD (Meyer et al., 2023). These benefits may foster teachers' motivation to choose and engage in professional development according to their interests and needs without location-related barriers.

The literature shows that online PD comprises both formal and informal activities (Carpenter and Krutka, 2014; Kyndt et al., 2016; Aguilar et al., 2021; Meyer et al., 2023). Formal online PD includes synchronous and asynchronous distance learning. Synchronous PD aims to replicate face-to-face PD experiences through live interaction with instructors or other participants, such as live chat or video conferencing. In contrast, in asynchronous PD, participants and instructors do not need to engage in course activities simultaneously; participants can access and complete the material at their own pace. Informal online PD refers to teachers' learning activities that occur outside formal programmes, such as using social media (e.g., Instagram or Twitter) to engage and interact with peers or colleagues.

Despite the benefits of online PD, the literature also identifies several challenges. Online PD that uses digital technologies, such as a learning management system (LMS), may make it difficult for participants to engage actively with the learning material (Meyer et al., 2023). When participants become passive during online PD, they may lose concentration and attention, resulting in distraction and a higher likelihood of dropping out prematurely (Geri et al., 2017; Meyer et al., 2023). Online PD may also provide limited opportunities for teachers to practise new learning methods or approaches (Meyer et al., 2023). In response to these challenges, it is necessary to investigate the quality attributes of professional development, particularly in the context of formal online PD.

Addressing the quality attributes of online PD using the Community of Inquiry framework

The CoI framework was proposed by Garrison, Anderson, and Archer in 1999. This framework identifies the crucial elements of a successful educational experience using computer-mediated communication (CMC) (Garrison et al., 1999). Later, the CoI framework was further developed for online distance education (Garrison et al., 2003; Carrillo and Flores, 2020). According to the CoI framework, online learning includes three crucial elements: social presence, cognitive presence, and teaching presence.

First, social presence refers to interaction among participants during online PD, such as sharing prior experiences or work through real-time forum discussions or video conferencing (Parsons et al., 2019; Meyer et al., 2023). Such interaction helps participants present themselves authentically, express their personal characteristics, and build interpersonal relationships with peers, leading to a collaborative environment during online PD training (Parsons et al., 2019; Carrillo and Flores, 2020). Social interactions in online PD allow participants to engage with the community and to develop and broaden their professional networks (Salmon et al., 2015; Parsons et al., 2019). Therefore, social presence in online PD may enable participants to establish a meaningful support network of peers and colleagues.

Second, cognitive presence refers to the capacity of participants to connect new knowledge with existing experiences in successful online learning (Garrison et al., 2001; Meyer et al., 2023). Cognitive presence also allows participants to construct meaning through continuous reflection and interaction with peers within a community of inquiry (Garrison et al., 1999; Carrillo and Flores, 2020). Meaning construction depends on individual learning competence and is enhanced by active engagement with peers. Through communication and interaction, participants can collectively exchange experiences and perspectives and shape their insights. Effective online learning can therefore be achieved by integrating material with prior knowledge, reflecting on beliefs, knowledge, and practices, and combining these processes with active community engagement to support deeper understanding.

Third, teaching presence refers to the instructor's role in designing and facilitating online learning activities to help participants achieve learning outcomes (Carrillo and Flores, 2020; Meyer et al., 2023). It includes establishing clear objectives and core course components and helping participants engage in goal-setting (Wendt and Courduff, 2018; Parsons et al., 2019; Carrillo and Flores, 2020). Teaching presence also involves the instructor's role in designing the learning experience, including selecting, organising, and presenting course content (Garrison et al., 1999).

This study used the CoI framework to address the quality attributes of online PD. The three crucial elements of the CoI framework were operationalised as follows: (1) social presence was represented by collaborative activities among participants (teachers) during online PD; (2) cognitive presence was represented by cognitive activation during online PD, such as supporting participants in addressing pedagogical and practical challenges and prompting discussion within the community of inquiry; and (3) teaching presence was represented by the clarity and structure of online PD.

Effectiveness of online PD using the Kirkpatrick model

Training evaluation is crucial for determining the effectiveness of training and its impact on participants' knowledge and skills (Piryani et al., 2018; Savul et al., 2021). Many researchers use the Kirkpatrick model as a standard method for evaluating the effectiveness of training programmes in various fields, including education (Piryani et al., 2018; Alsalamah and Callinan, 2021; Limon, 2022), cybersecurity (Khan et al., 2023), virtual reality (Howard and Gutworth, 2020; Phillips et al., 2023), healthcare (Savul et al., 2021; Chia et al., 2022; Cheung et al., 2023), and the mining industry (de S. Bergamo et al., 2022).

The Kirkpatrick model proposes four levels for examining training effectiveness (Kirkpatrick and Kirkpatrick, 2016): (1) reaction, which gauges trainees' subjective responses to the training programme, such as satisfaction; (2) learning, which gauges trainees' acquisition of knowledge and skills from the training programme; (3) behaviour, which gauges observable changes in trainees' demonstrations resulting from the knowledge and skills acquired after the training programme; and (4) results, which gauges the broader intended impact of the training programme on the organisation through trainees' job performance.

In line with the Kirkpatrick model, other studies have proposed that several levels can be used to measure teacher PD effectiveness: (1) teacher satisfaction with or acceptance of PD; (2) teacher cognition or changes in professional practice, such as changes in beliefs, knowledge, motivation, and classroom practices; and (3) student achievement (Lipowsky and Rzejak, 2015; Kalinowski et al., 2020).

To delimit and simplify the measurement of online PD effectiveness, this study used two levels of the Kirkpatrick model: reaction, represented by satisfaction with online PD, and behaviour, represented by the impact of online PD on changes in professional practice.

Current study

As explained in the background and theoretical framework, this study examines the quality attributes of online PD using the CoI framework, including collaboration to address social presence, cognitive activation to address cognitive presence, and clarity and structure to address teaching presence. Furthermore, it uses satisfaction and changes in professional practice as two levels of the Kirkpatrick model to examine online PD effectiveness. Finally, the study examines the link between online PD quality, satisfaction, and changes in teachers' professional practice. Accordingly, the following research questions (RQs) are proposed:

1. What are the quality attributes of online PD?
2. What is the effectiveness of online PD from teachers' perspectives?
3. What is the link between the quality of online PD and satisfaction?
4. What is the link between the quality of online PD and changes in teachers' professional practice?

METHOD

Procedures and participants

This study was conducted from July to November 2025. It involved senior high school economics teachers in Indonesia representing five major islands: Java, Papua, Kalimantan, Sumatra, and Sulawesi. Research approval was sought from the Indonesian Economics Teacher Association to recruit its members as research participants. After approval was granted, the association provided data containing names, email addresses, and school names. Purposive sampling was employed to identify and recruit teachers who had participated in online PD activities during the previous 12 months, which constituted the eligibility criterion for participation in this study. An online invitation was sent by email to 640 selected teachers. The invitation described the research objectives, ensured anonymity, clarified that the data would be collected for research purposes only, and stated that participation was voluntary. A total of 247 teachers responded and participated in the research (response rate:

38.59%). We excluded 41 participants because they did not fulfil the criteria for TPD attendance and/or had incomplete data sets. Therefore, the final sample comprised 206 teachers, dominated by females (63.39%) compared with males (36.61%). On average, the participants were 38.2 years old and had 12.7 years of teaching experience.

Instruments

The study used instruments developed in previous research. The instruments were slightly modified to fit the research context. All instruments were translated into Indonesian (Bahasa Indonesia) and reviewed by experts in both Bahasa Indonesia and education to prevent misinterpretation by the participants.
The instruments developed by Meyer et al. (2023) were used to measure three quality attributes of online PD (collaboration, cognitive activation, and clarity and structure) and changes in professional practice. The online PD quality attributes comprised eleven items, while changes in professional practice were measured using four items. Finally, satisfaction with online PD was measured using the Online Course Satisfaction Scale (OCSS) developed by Wei and Chou (2020), which consists of four items. All questionnaires used a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Data analysis

After data collection, data screening was performed to prevent biased analysis. Of the 247 research participants, 41 were removed because they did not meet the TPD attendance criterion and/or had incomplete responses. Structural equation modelling (SEM) with the partial least squares approach was then performed to examine the relationships among variables. The multiple-step procedure proposed by Hair et al. (2014) was adopted for the partial least squares approach. This procedure includes model specification, outer model evaluation (validity and reliability of construct measurement), and inner model evaluation (R2, Q2, f2, and path coefficients).

RESULTS

Outer model evaluation

To evaluate the outer model, the validity and reliability of each construct and measurement were examined. First, the convergent and discriminant validity of the constructs were evaluated. The results (Table 1) show that all construct measurement items had loading factors higher than 0.7 and that the AVE of each construct was higher than 0.5, indicating that convergent validity was established (Hair et al., 2014; Hair et al., 2017; Hair and Alamer, 2022). Furthermore, the measurement model test generated the Heterotrait-Monotrait Ratio (HTMT) to evaluate discriminant validity. The results (Table 2) show that all HTMT values were below the conservative threshold of 0.85 (Hair et al., 2017; Sarstedt et al., 2017; Hair and Alamer, 2022), indicating that the measurement model met the discriminant validity criteria.

Constructs	Item	Mean	VIF	Loading	AVE
Collaboration (Col)	Col1	3.273	2.719	0.897	0.791
	Col2	3.455	2.414	0.888	
	Col3	3.545	2.000	0.883	
Overall mean score of construct Col		**3.424**			
Cognitive activation (CA)	CA1	3.455	2.437	0.866	0.802
	CA2	3.636	2.602	0.934	
	CA3	3.545	3.037	0.889	
	CA4	3.455	3.087	0.890	
Overall mean score of construct CA		**3.523**			
Clarity and structure (CS)	CS1	3.955	3.075	0.961	0.760
	CS2	3.591	3.876	0.942	
	CS3	3.591	3.290	0.764	
	CS4	3.545	2.248	0.803	
Overall mean score of construct CS		**3.670**			
Satisfaction (Sa)	Sa1	3.636	2.297	0.727	0.632
	Sa2	3.818	4.085	0.731	
	Sa3	3.909	1.585	0.764	
	Sa4	3.959	2.251	0.939	
Overall mean score of construct Sa		**3.831**			
Changes in professional practices (CPP)	CPP1	3.682	4.110	0.865	0.788
	CPP2	3.818	3.799	0.918	
	CPP3	3.364	3.575	0.972	
	CPP4	3.364	2.744	0.785	
Overall mean score of construct CPP		**3.557**			

Table 1: Mean, VIF, loading factor, and AVE (first-order measurement model)

	Collaboration	Cognitive activation	Clarity and structure	Satisfaction	Change in professional practices
Collaboration	-	-	-	-	-
Cognitive activation	0.484	-	-	-	-
Clarity and structure	0.545	0.517	-	-	-
Satisfaction	0.748	0.714	0.638	-	-
Change in professional practices	0.502	0.508	0.464	0.699	-

Table 2: Discriminant validity (Heterotrait-Monotrait Ratio / HTMT)

Second, the reliability of the construct measurement model was evaluated. The results (Table 3) show that Cronbach's alpha and composite reliability for each construct were higher than 0.7, indicating that all measurement models in this study had internal consistency reliability (Hair et al., 2014; Hair et al., 2017).

	Cronbach's Alpha	Composite reliability
Collaboration	0.868	0.919
Cognitive activation	0.917	0.942
Clarity and structure	0.891	0.926
Satisfaction	0.803	0.872
Change in professional practices	0.909	0.937

Table 3: Reliability

According to the theoretical framework explained previously, the quality of online PD consists of three dimensions: collaboration, cognitive activation, and clarity and structure. Therefore, a second-order measurement model was performed for the online PD quality variable. The results (Table 4) show that the validity indicators (loading factor and AVE) and reliability indicators (Cronbach's alpha and composite reliability) of the measurement model for the online PD quality variable were established.

Variable	Dimensions	Loading factor	AVE	Cronbach's Alpha	Composite reliability
Quality of online PD	Collaboration	0.720	0.517	0.901	0.918
	Cognitive activation	0.827			
	Clarity and structure	0.835			

Table 4: Second-order measurement model

Inner model evaluation

After the measurement model was established, the study proceeded to the next stage: structural model evaluation (inner model). According to Hair et al. (2014), inner model evaluation considers the coefficient of determination (R^2), cross-validated redundancy (Q^2), effect size (f^2), and path coefficients. Nevertheless, the measurement model must first be free from high correlations among constructs (i.e., collinearity bias). The results (Table 1) show VIF values ranging from 1.585 to 4.110, below the threshold value of 5, indicating that collinearity in the measurement model did not reach critical levels (Hair et al., 2017).

Table 5 shows that the R^2 values were 0.579 and 0.501, indicating that the exogenous construct (quality of online PD) had moderate predictive power (Hair et al., 2017; Hair et al., 2019). In other words, the quality of online PD explained 57.9% and 50.1%, respectively, of the variance in satisfaction and changes in professional practice. Furthermore, the predictive accuracy of the research model was assessed through cross-validated redundancy (Q^2). The results show that the Q^2 values for satisfaction and changes in professional practice were 0.326 and 0.242, indicating that the model had medium predictive relevance (Hair et al., 2017; Hair et al., 2019). The f^2 values (effect sizes) of the quality of online PD were 0.526 and 0.418 for satisfaction and changes in professional practice, respectively. These values indicate that the quality of online PD had a large effect size on the endogenous constructs of satisfaction and changes in professional practice (Hair et al., 2017; Hair et al., 2019), with the effect size being larger for satisfaction than for changes in professional practice.

Finally, path coefficients were examined to determine the significant effects of online PD quality on satisfaction and changes in professional practice. The results (Table 6 and Figure 1) show that all path coefficients in the research model had positive values and were significant at $p < 0.01$.

Relationship	R^2	Q^2	f^2
Quality of online PD → Satisfaction	0.579	0.326	0.526
Quality of online PD → Change in professional practices	0.501	0.242	0.418

Table 5: Predictive power/accuracy

Relationship	Coefficients	S.E.	*p*-value
Quality of online PD → Satisfaction	0.720	0.058	0.000
Quality of online PD → Change in professional practices	0.684	0.120	0.000

Table 6: Path coefficients

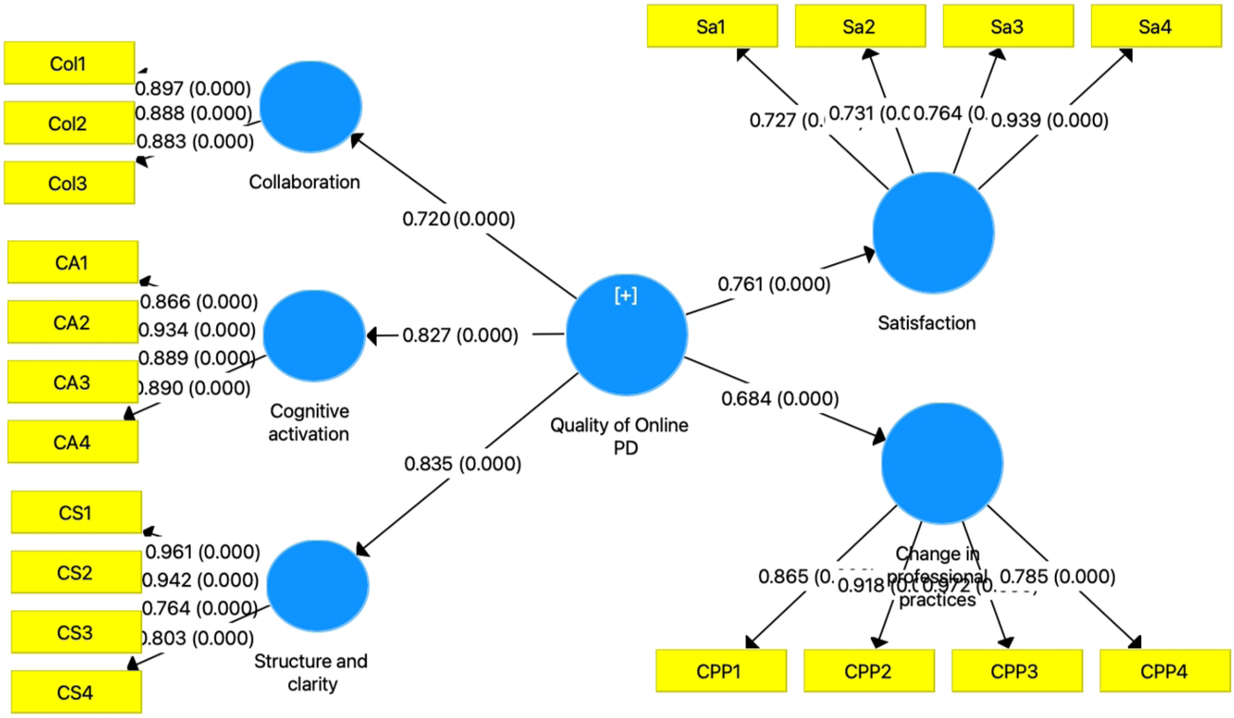

Figure 1: Result of structural model analysis

DISCUSSION

Following the proposed RQs, the study investigated online PD quality attributes using the CoI framework. It also assessed the effectiveness of online PD using the Kirkpatrick model: the reaction level through participants' satisfaction and the behaviour level through changes in teachers' professional practice. Finally, the study examined the influence of online PD quality on satisfaction and changes in professional practice. The findings are discussed below.

What are the quality attributes of online PD?

To address the quality attributes of online PD, the study used the CoI framework from Garrison et al. (1999). According to the CoI framework, online distance education consists of three crucial elements: social presence, cognitive presence, and teaching presence (Garrison et al., 2003; Carrillo and Flores, 2020). Accordingly, collaboration was used to represent social presence, cognitive activation to represent cognitive presence, and clarity and structure to represent teaching presence. The results of the second-order measurement model in Table 4 and Figure 1 show that the three quality attributes of online PD (collaboration, cognitive activation, and clarity and structure) had loading scores above 0.70, AVE greater than 0.5, and Cronbach's alpha and composite reliability greater than 0.7. These findings indicate that collaboration, cognitive activation, and clarity and structure contribute to explaining and establishing the quality of online PD. Statistically, therefore, the current study confirmed the CoI framework, which proposes three crucial elements in online learning: collaboration, cognitive activation, and clarity and structure (Garrison et al., 1999; Garrison et al., 2003).

Collaboration during online PD allows participants to share teaching experiences, discuss best practices and new learning methods, build interpersonal interactions, and broaden their professional networks. This finding aligns with previous studies that viewed collaboration as a crucial feature and effective approach in online learning courses that positively contributes to participants' experiences (Vinagre, 2017; Theelen et al., 2020). As proposed by the communities of practice framework, individuals develop their knowledge, beliefs, attitudes, and skills within social and cultural contexts rather than in isolation (Butler et al., 2004). Therefore, this study confirms that collaboration substantially fosters teachers' professional knowledge in online PD and is crucial to online PD quality.

The current study also found that cognitive activation in online PD stimulates participants' involvement in learning courses by encouraging them to communicate and discuss their teaching experiences and challenges. Cognitive activation also provides teachers with opportunities to construct new knowledge by linking it with their own and their peers' prior experiences through reflection on existing practices. These findings strengthen previous studies suggesting that discussing teaching experiences is crucial for understanding teaching problems and constructing professional teaching knowledge (Fletcher and Bullock, 2015; Carrillo and Flores, 2020). Cognitive activation in online PD also fosters participants' engagement during the course. When online PD offers new knowledge about professional approaches, high course engagement may make it easier for participants to welcome, improve, or change their beliefs and knowledge. This finding aligns with adult learning theories, which propose that adults learn differently from children and must be active participants in the course learning process to achieve learning goals (Trotter, 2006). Therefore, this study indicates that cognitive activation is crucial in establishing online PD quality.

Finally, this study revealed that clarity and structure in online PD are crucial aspects from participants' perspectives. Online PD may have more weaknesses than offline PD, such as offering limited opportunities for participants to practise new teaching models or share ideas and experiences (Carrillo and Flores, 2020; Meyer et al., 2023). Other studies have indicated that online learning courses often rely primarily on lectures, which can lead participants to receive information passively and reduce their focus (Parsons et al., 2019; Scagnoli et al., 2019; Meyer et al., 2023). This study found that when online PD has clear objectives and structure, for which the instructor or course designer is responsible, participants are more likely to participate actively and remain attentive. This finding aligns with previous evidence showing that participants are more motivated when courses provide clear objectives and facilitate participation during online learning (Parsons et al., 2019; Carrillo and Flores, 2020). Therefore, designing clear objectives and choosing appropriate approaches to help participants achieve learning goals confirms that clarity and structure are quality attributes of online PD.

What is the effectiveness of online PD from teachers' perspectives?

Reaction level (satisfaction with online PD)

This study assessed the effectiveness of online PD using the Kirkpatrick model, specifically the reaction level (satisfaction) and behaviour level (changes in professional practice). For satisfaction, the research scale consisted of four items covering participants' reactions to the trainer/instructor and to the content and delivery of the training. The results in Table 1 show a mean satisfaction score of 3.831, which can be categorised as above moderate. This indicates that the participants were satisfied with the online PD in which they enrolled.

More specifically, the findings (Sa1 and Sa2 in Table 1) show an average score of 3.727, suggesting that participants were satisfied with the instructor during the online PD course. This finding aligns with previous studies proposing that participants' satisfaction is crucial in establishing effective training (Sitzmann et al., 2008; Alsalamah and Callinan, 2021). Another study showed that trainees' reactions to their training instructor, including likes or dislikes, predict satisfaction and motivation during the course (Marsh and Overall, 1980). Furthermore, effective training is also determined by the quality of the trainer or instructor (Boyd et al., 2017; Alsalamah and Callinan, 2020), and participants' perceptions of training are strongly influenced by the instructor's performance (Morgan and Casper, 2000).

Regarding participants' reactions to content and training delivery, the findings (Sa3 and Sa4 in Table 1) show an average score of 3.934, indicating that participants were satisfied. The current study found that participants considered the content and materials of online PD (Sa2) and the delivery methods (Sa3) important. These findings correspond to previous studies suggesting that effective training should combine theoretical and practical content (Gauld and Miller, 2004; Giangreco et al., 2009) and multiple delivery methods (King et al., 2000; Brauckmann and Pashiardis, 2012). Combining theoretical and practical content is more effective for transferring new knowledge and skills and for increasing trainee satisfaction. Furthermore, using multiple delivery methods can sustain participants' interest and curiosity during the course, as individuals have different learning styles.

Behaviour level (changes in professional practice)

At this level, four items were used to measure changes in professional practice. The items addressed gaining new pedagogical and content knowledge, expanding professional networks, feeling more confident in teaching practices, and addressing professional challenges. Table 1 shows that the mean score was 3.557 (moderate). This result indicates that online PD could support changes in professional practice, meaning that teachers can apply new knowledge, teaching methods, and approaches acquired from online PD to their teaching practices. Through online PD, teachers can also expand their professional networks, increase their confidence in teaching practice, and identify challenges in carrying out their duties. These findings correspond to previous studies showing that professional development can facilitate the acquisition of new teaching skills, strategies, and insights (Jacob et al., 2017; Egert et al., 2018; Sims et al., 2021; Abakah, 2023), thereby enhancing teaching performance. Participation in professional development also expands teachers' professional networks (Abakah, 2023), increases teachers' confidence in demonstrating new skills in appropriate situations, and helps them deal with job responsibilities, job demands, and job-related problems (Noe, 1986; Alsalamah and Callinan, 2021). Professional development programmes also help teachers foster their teaching creativity (Alsalamah and Callinan, 2021). In summary, online PD was effective, as reflected in participants' satisfaction with online PD and changes in professional practice. The participants generally reported satisfaction with online PD, including satisfaction with the instructor, content, and delivery method. Furthermore, they also reported changes in professional practice, including the acquisition of new pedagogical knowledge, expansion of professional networks, increased confidence in teaching practice, and support in dealing with professional challenges.

What is the link between the quality of online PD and satisfaction?

This study revealed that the quality of online PD was positively related to satisfaction (Table 6 and Figure 1). This indicates that the higher the online PD quality, reflected in the three attributes of collaboration, cognitive activation, and clarity and structure, the higher the satisfaction of online PD participants. More specifically, the study identified how each online PD quality attribute affects participants' satisfaction. The first attribute is collaboration. The findings indicate that collaboration among participants during online courses positively fosters satisfaction. Through interaction and collaboration during online PD, teachers receive helpful suggestions, comments, and peer feedback. This finding aligns with previous studies showing that peer interaction is related to learner satisfaction in online learning courses (Kuo et al., 2013; Gameel, 2017; Pham and Nguyen, 2021). Another study also found that peer interaction motivates learners in online learning environments (Ghadirian et al., 2018). Interactions among online participants lead to a collaborative environment during the course and broaden professional networks. Therefore, collaboration, as part of the quality attributes of online PD, plays a crucial role in participants' satisfaction.

The second attribute is cognitive activation. This study found that teachers who perceived that their online PD enabled them to construct meaning through continuous reflection and by linking their experience with new knowledge felt more satisfied than those who did not perceive this. The study also revealed that teachers felt satisfied when online PD presented challenging learning situations. Such situations stimulate teachers' higher-order thinking skills and support the achievement of learning goals, such as enhancing participants' pedagogical and content knowledge. Participants perceived this as a factor that supported their satisfaction with online PD. These findings confirm previous studies identifying the substantial role of perceived instructional quality in online learning and its close relationship with learner satisfaction (Pham and Nguyen, 2021; Taghizadeh and Hajhosseini, 2021; Yang et al., 2023).

The third attribute is clarity and structure. The study found that participants who perceived the online course as having clear objectives and a well-structured design reported higher satisfaction than those who did not. This can be explained as follows: when a course is well organised, with clear objectives, logical progression, and effective communication of information, participants are more likely to feel engaged, understand the content, and experience a sense of accomplishment. A structured course provides a framework that helps participants navigate the learning material, leading to a more satisfying educational experience. Conversely, poorly structured courses may cause participants to feel frustrated, confused, and less satisfied. Therefore, a course's structure and clarity are crucial in shaping participants' satisfaction with the learning experience. These findings confirm previous studies showing that well-structured courses and clear learning goals are associated with higher satisfaction among online PD participants (Swan, 2001; Palmer and Holt, 2009; Reeves and Pedulla, 2011). In summary, the quality of online PD is positively associated with participants' satisfaction: the higher the quality of online PD, the higher the participants' satisfaction.

What is the link between the quality of online PD and changes in teachers' professional practice?

According to Table 6 and Figure 1, online PD quality was positively related to changes in teachers' professional practice. This finding indicates that higher online PD quality is associated with greater changes in professional practice. More specifically, the study explains how each attribute of online PD quality affects the outcome variable. The first attribute is collaboration. The findings show that teachers tend to change their professional practices, such as applying new pedagogical knowledge, when online PD allows participants to collaborate with one another by sharing teaching experiences and discussing best practices and new learning methods. This finding corresponds with previous studies showing that collaboration with peers or communities during professional development programmes makes teachers more likely to apply what they have learned in actual teaching scenarios (Desimone, 2009; Sims and Fletcher-Wood, 2021; Teslo et al., 2023).

The second attribute is cognitive activation. Respondents who perceived online PD as providing challenging learning delivery and enabling them to construct new knowledge by linking it with prior experiences reported greater changes in professional practice, such as using new knowledge in teaching. Engaging in challenging learning experiences enhances the likelihood of constructing and applying new pedagogical knowledge from professional development programmes in actual teaching situations. Furthermore, when online PD is designed to support new knowledge construction by connecting prior experience through reflection and peer discussion, participants are more likely to master course content and apply it in teaching. This finding confirms previous studies showing that cognitive activation in courses or training is positively related to gains in participant achievement (Praetorius et al., 2018), insightful learning processes (Baumert and Kunter, 2013), and cognitive restructuring of science concepts (Fauth et al., 2019).

The final attribute is clarity and structure. This study found that respondents who positively perceived online PD as well structured and guided by clear objectives reported greater changes in their pedagogical knowledge, particularly regarding current teaching methods and strategies. A well-structured course facilitates effective learning experiences for participants. It provides clear learning objectives, appropriate learning material, suitable learning delivery, and assessments. This enhances the learning environment and helps course participants achieve the desired learning outcomes. Achieving learning outcomes after participating in a teacher professional development (TPD) programme increases the likelihood of teaching practice improvement. These findings confirm previous research showing that clarity and structure are important features in establishing effective teaching and enhancing teachers' knowledge and teaching practices (Lipowsky and Rzejak, 2015). The findings also align with research showing that effective TPD is determined by changes in teachers' knowledge and teaching practices (Kalinowski et al., 2020).

In summary, the study shows that the quality of online PD, attributed to collaboration, cognitive activation, and clarity and structure, positively affects changes in teachers' professional practice. These findings align with the literature on transformative TPD approaches, which are a standard goal in designing TPD. Transformative approaches refer to TPD strategies and methods that focus on changing teachers' knowledge, skills, attitudes, and practices (Kennedy, 2005; Kennedy, 2014; Teslo et al., 2023). The findings also strengthen previous studies proposing that effective teacher professional development can be measured by teacher satisfaction and changes in teacher beliefs, knowledge, motivation, and classroom practices (Lipowsky and Rzejak, 2015; Kalinowski et al., 2020).

Although the current model treats satisfaction and changes in professional practice as two independent outcome variables, a potential relationship between them should also be acknowledged. Conceptually, teachers who are more satisfied with online PD may demonstrate greater motivation, engagement, and willingness to apply newly acquired pedagogical knowledge in their professional practice. Previous training evaluation literature also suggests that positive participant reactions may facilitate behavioural transfer and implementation outcomes. However, the present study did not examine the direct relationship between satisfaction and changes in professional practice because the model focused specifically on the direct effects of online PD quality. Therefore, future studies are encouraged to investigate whether satisfaction mediates or strengthens the relationship between online PD quality and changes in professional practice.

Overall, the current findings imply that the effectiveness of online PD does not reside merely in technology delivery, but rather in the extent to which the online learning environment facilitates meaningful collaboration, cognitive engagement, and instructional clarity. Furthermore, the findings should be interpreted in light of the study's methodological limitations, including the relatively small sample size and the cross-sectional nature of the data. Future studies are recommended to refine the current model, including the possibility that satisfaction is an antecedent or mediator of changes in professional practice.

CONCLUSION AND IMPLICATIONS

In conclusion, the current study confirmed that three attributes establish the quality of online PD: collaboration, cognitive activation, and clarity and structure. Furthermore, the study found that online PD is effective in enhancing teacher knowledge and skills, as seen from the reaction level (participant satisfaction) and behaviour level (changes in professional practice). Finally, the study shows that the quality of online PD positively affects participants' satisfaction and changes in teachers' professional practice.

This study provides both theoretical and practical contributions. Regarding theoretical contributions, it confirmed the CoI framework for successful distance education (Garrison et al., 1999; Garrison et al., 2003), the Kirkpatrick model for training programme evaluation (Kirkpatrick and Kirkpatrick, 2006; Kirkpatrick and Kirkpatrick, 2016), and the relationship between online PD quality, satisfaction, and changes in teachers' professional practice. The study extends understanding of online PD, particularly its quality attributes. As previous research has explained, unlike offline PD, limited evidence is currently available on the quality attributes of online PD (Meyer et al., 2023). This study shows that the quality attributes of online PD consist of collaboration, cognitive activation, and clarity and structure, which represent the three elements of the CoI framework: social presence, cognitive presence, and teaching presence, respectively. It provides evidence supporting the effectiveness of online teacher professional development in augmenting teachers' knowledge and skills. Furthermore, the study found that online PD quality is closely related to satisfaction and changes in teachers' professional practice. The findings strengthen previous research showing that effective teacher professional development is related to teacher satisfaction and changes in teachers' beliefs, knowledge, motivation, and classroom practices (Lipowsky and Rzejak, 2015; Kalinowski et al., 2020).

Regarding practical contributions, the findings indicate that three crucial elements—social presence, cognitive presence, and teaching presence — contribute to the quality and effectiveness of online PD. Therefore, TPD providers, including government and private institutions, should ensure that these three elements are present in online PD. The government should also offer online PD to support teachers who may face barriers to attending offline TPD sessions because of financial constraints, time limitations, or residence in remote areas. By providing online TPD, teachers can stay updated on the latest advancements in knowledge and skills, supporting continuous professional growth. This recommendation is based on the findings that online PD can effectively support teachers' professional learning and professional practice. Nevertheless, further comparative research is needed to examine how its effectiveness differs from or aligns with that of traditional offline PD.

LIMITATIONS

This study has several limitations. First, to evaluate the effectiveness of online PD, it used only two of the four evaluation levels offered by the Kirkpatrick model: the reaction level (satisfaction) and the behaviour level (changes in professional practice). Future research should evaluate the effectiveness of online PD using all four levels of the Kirkpatrick model to provide more robust results. Second, this study used a relatively small sample size of 206 and a complex model (SEM-PLS with higher-order analyses). Although the PLS approach allows for estimation of the proposed structural model with a smaller sample size (Hair and Alamer, 2022), the findings should be interpreted with caution, particularly regarding their generalisability. Therefore, future research should use a larger sample size to improve the robustness, external validity, and generalisability of the research model. Third, this research overlooked participants' gender background, although various studies highlight the impact of gender on both life and job satisfaction (Okpara et al., 2005; Jovanović, 2017; Joshanloo and Jovanović, 2020). Fourth, the study used a cross-sectional design to address the research questions. Future studies should therefore consider demographic factors and employ a longitudinal research design for more robust validation of the findings.

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Full research paper

MOOD STATES AND STUDENT LEARNING IN PROJECT MANAGEMENT: VALIDATING AND EXTENDING PRIOR RESEARCH WITH NEW DATA

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ABSTRACT

Practical experience is a key component of teaching and learning in project management. In 2023–2025, we organized two practical project management seminars as part of a bachelor's introductory project management course. In these seminars, we used serious management games to practise waterfall and agile approaches and to improve students' teamwork, communication, and soft skills. We applied the Profile of Mood States method to evaluate changes in total mood and individual mood factors during the seminars. We collected and analysed data from 2024–2025 (n_{24} = 139, n_{25} = 98) and compared these results with prior findings from 2023 (n_{23} = 49). We found that students' total mood improved significantly during both waterfall and agile seminars in all eligible years. Fatigue, depression, and confusion decreased significantly for both seminar types in all years, and tension decreased in most seminars. We will use these results to further improve the practical seminars and to introduce the solution to other areas.

KEYWORDS

Education, project management, Profile of Mood States, Scrum, serious management games

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Highlights

- *We organized practical project management seminars for students in 2023–2025.*
- *We used serious waterfall and agile project management games in the seminars.*
- *Participants' total mood improved during waterfall and agile seminars in all years.*
- *Fatigue, depression, and confusion decreased during waterfall and agile seminars in all years.*

INTRODUCTION AND LITERATURE REVIEW

In our prior research, we conducted a pilot study with a limited number of participants in 2023 to determine whether the serious management games used in practical seminars had a positive impact on mood, teamwork, and performance (Kunhart and Bartoška, 2025). We now aim to support and reinforce these findings using new datasets and to extend the research by providing a detailed analysis of individual mood factors. In this section, we describe the necessary background and context leading to the research gap and objectives addressed in this study.

Project management

Project management is a structured discipline concerned with the planning, execution, and control of temporary endeavors undertaken to achieve defined objectives within constraints of time, cost, and scope Project Management Institute (2026). It can also be understood as the application of specific processes and principles to initiate, plan, execute, and manage how new initiatives or changes are implemented within an organization (AXELOS, 2023). As organizations increasingly operate in complex and dynamic environments, effective project management has become a critical competency across a broad range of industries, including construction, manufacturing, software development, and public administration. The growing demand for skilled project managers has, in turn, placed considerable pressure on higher education institutions to provide not only theoretical instruction but also experiential learning opportunities that mirror professional practice. Moreover, the behavior of individual human agents within project activities has a decisive influence on project outcomes, as responses to deadlines and workload are shaped by phenomena such as Student syndrome and Parkinson's law (Bartoška and Šubrt, 2012). At the methodological level, project management approaches can be classified along a spectrum ranging from plan-driven to change-driven paradigms. The plan-driven, or waterfall, model traces its conceptual roots to Royce (1987), who described a sequential, phase-gated development process in which each stage, namely requirements, design, implementation, verification, and maintenance, is completed before the next begins. Its strengths lie in environments where requirements are well defined and unlikely to change during the project. However, its inherent rigidity makes it less suitable for projects characterized by uncertainty, evolving stakeholder needs, or the need for rapid iteration.

In response to these limitations, which culminated in the software development crisis of the 1990s (Shore, 2021), the software industry developed a fundamentally different philosophy of project delivery, articulated in the Agile Manifesto (Beck et al., 2001). Agile prioritizes individuals and interactions, working software, customer collaboration, and responsiveness to change. Among the agile frameworks that have since emerged, Scrum has become the most widely adopted in professional practice in software development and other fields (Digital.ai, 2024; Hobbs and Petit, 2017; Hron and Obwegeser, 2022). Scrum structures project work into short, time-boxed iterations called Sprints, with clearly defined roles and a set of events, including Planning, Daily Scrum, Reviews, and Retrospectives (Schwaber and Sutherland, 2012; Sutherland, 2014). This iterative cadence fosters continuous feedback, adaptive planning, and a high degree of team autonomy. Empirical evidence suggests that agile projects tend to outperform their waterfall counterparts in schedule adherence and stakeholder satisfaction, particularly in software-intensive domains (Chow and Cao, 2008; Prasetya et al., 2021), although the effectiveness of either approach remains contingent on organizational context, team maturity, and the nature of the project (Ciric et al., 2019).

The distinction between waterfall and agile reflects fundamentally different assumptions about how teams organize, communicate, and respond to uncertainty. Waterfall projects tend to involve clearly delineated individual responsibilities and infrequent cross-functional collaboration, whereas agile teams are expected to self-organize, continuously negotiate priorities, and maintain high levels of interpersonal coordination across short delivery cycles (Dingsøyr et al., 2012). These structural differences give rise to distinct patterns of cognitive load, emotional engagement, and social dynamics among team members, including opinion formation and consensus-building processes within small groups (Horáček, 2025), all of which are difficult to convey through lecture-based instruction alone. Effective preparation for professional project management therefore requires direct exposure to both paradigms, ideally within a controlled learning environment that preserves the essential characteristics of each approach while allowing for systematic observation and assessment (Hellström et al., 2023; Rumeser and Emsley, 2019). We designed the practical seminars with this rationale in mind: to immerse students in authentic waterfall and agile project experiences and to evaluate the behavioral and affective outcomes of that immersion using a validated psychometric instrument.

Profile of Mood States overview

The Profile of Mood States (POMS) is a psychological rating scale and method designed to measure transient moods and evaluate changes in mood states. McNair et al. (1971) developed and introduced the original POMS in 1971. POMS moods are short-term states that affect human behavior, health, and well-being; they are often unrelated to external events and can vary in intensity (Searight and Montone, 2017). POMS allows for a quick and efficient assessment of changes in participants' mood states during the assessed activity. The method is used through interventions consisting of two variants. Each participant completes the first questionnaire (variant A) before the observed activity and the second questionnaire (variant B) after the activity. Each questionnaire takes 5–10 minutes to complete. Jones et al. (2010) note that multiple interventions are commonly used to evaluate mood changes over a specific period. POMS has been used in more than four thousand published studies (Bourgeois et al., 2010). The original version of POMS was intended for adults and included 65 questions. It was subsequently revised and adapted to specific needs. In 1983, Shacham published POMS-SF, which includes 37 questions and addresses shortcomings of the original version, particularly its excessive length, while maintaining reliability and accuracy. Curran et al. (1995) validated POMS-SF and stated that it can be considered an excellent alternative to the original POMS when a brief measure of psychological distress is required. In 2012, Heuchert and McNair published a revised version, POMS 2 (Heuchert and McNair, 2012). However, unlike earlier versions, the POMS 2 scoring keys and instructions are proprietary, and both paper and online questionnaires must be evaluated exclusively using the publisher's online tool (Boyle et al., 2015). POMS is chiefly used to assess mood changes in sports, such as athletics and general physical activity (Berger and Motl, 2000; Heikura et al., 2023; Pang et al., 2023). Research shows that physical activity is positively related to mood states and perceived health, with moderate physical activity showing particular benefits for psychological well-being (Reigal et al., 2021). Beyond sports, researchers have used the method in diverse fields, ranging from management and decision-making, where human factors remain central to operations research and management science (Weber et al., 2020), to investigations of building occupants' perceptions of thermal environments (Özbey and Turhan, 2025). Since its introduction in 1971, other POMS variants have emerged, including POMS-Fatigue by Johnson et al. (2019) and POMS-16, a 16-item version for brief and cost-effective assessment by Petrowski et al. (2025). POMS has been adapted and validated in more than 42 languages (Boyle et al., 2015). The Czech version of POMS by Stuchlíková et al. (2005) is based on POMS-SF. The authors tailored and psychologically verified the Czech version for Czech target groups. The questions in the Czech questionnaire may differ from exact translations of the original POMS questions. A complete list of questions in the original and Czech versions of POMS is provided in Table 9 in Appendix A.

Serious management games

A serious game is a game intended for purposes beyond entertainment, typically with educational, training, or simulation objectives. According to De Gloria et al. (2014), serious games are attracting increasing interest in education and training because they can contextualize players' experiences in challenging, realistic environments and promote situational learning. In management, serious management games are used to develop skills and knowledge relevant to project management practice (Djaouti et al., 2011). In project management, management games involve hands-on building activities that provide firsthand experience and improve skills that are difficult to teach through traditional methods (Hellström et al., 2023). Serious management games are also valuable tools for gamifying leadership learning. By providing an engaging learning environment, these games can significantly improve the development of leadership and soft skills (Kesti et al., 2022). Active learning in project management encourages collaboration, teamwork, and project simulation through management games and practical experience (Paasivaara and Lassenius, 2014; Miller and Vaca Núñez, 2022). Key elements of effective management games include realism, feedback loops, adaptability, communication, and personalization.

Rumeser and Emsley (2019) recommend that researchers and educators move toward simulating soft project knowledge areas. In addition, management games are used to create risk-free experimental settings (Hellström et al., 2023), unlike real-world projects where delayed or expedited activities carry tangible penalties and bonuses that affect team performance (Branzei et al., 2011). In agile contexts, serious project management games often involve physical building activities using building kits (Paasivaara et al., 2014; Barcelos Bica and Gouvea da Silva, 2020) and office tools such as paper, scissors, and crayons to teach agile principles and help students understand concepts of agile and the Scrum method (Havazík and Pavlíčková, 2020). Studies focused on serious games in project management have shown that these games can lead to educational changes, such as a shift toward active pedagogies, the development of new soft-skill competencies, and changes in teacher-student relationships (Jaccard et al., 2022). Young Illies and Stachowski (2020) report that students often receive limited teamwork training, but when they do receive such training, it is well received. Fernandes et al. (2021) suggest that research on the application of Scrum in education remains scarce and mostly exploratory, and that empirical studies using Scrum to improve learning in higher education are rare.

Research gap and objectives

Our research goal is to verify and strengthen the results of our 2023 pilot study using new datasets from 2024 and 2025. The research gap lies in the lack of studies that use POMS to this extent in project management education or practice. To fulfill our research goal, we formulated three research questions:

- RQ1: Did the total mood of participants improve during the waterfall and agile project management seminars?
- RQ2: Did any individual factors improve significantly during the waterfall and agile project management seminars?
- RQ3: Are the results of total mood improvement consistent across all years in which we conducted the current and prior research?

We formulated RQ1 similarly to our prior research to support and reinforce our previous findings from 2023 using new datasets from seminars in 2024 and 2025. We added RQ2 to investigate changes in all factors. Finally, we added RQ3 to reflect and support the main research goal. We formulated four null and four alternative hypotheses to support our research questions. The null hypotheses are:

- $H1_0$: Total mood of participants did not improve during waterfall seminars.
- $H2_0$: Total mood of participants did not improve during agile seminars.
- $H3_0$: the factor did not improve during waterfall seminars.
- $H4_0$: the factor did not improve during agile seminars.

The related alternative hypotheses are:

- $H1_1$: Total mood of participants improved during waterfall seminars.
- $H2_1$: Total mood of participants improved during agile seminars.
- $H3_1$: the factor improved during waterfall seminars.
- $H4_1$: the factor improved during agile seminars.

Hypotheses H1 and H2 support RQ1 and are consistent with prior research. Hypotheses H3 and H4 support RQ2 and partially correspond to the part of prior research that examined only vigor and fatigue. We tested hypotheses H3 and H4 separately for each factor. We tested all hypotheses for both years and datasets, i.e., 2024 and 2025. For RQ3, we answered the research question by comparing the results between years. Our research reinforces our prior findings and contributes to improving practical project management teaching.

MATERIALS AND METHODS

POMS method

We used the POMS method to calculate TMD and factor scores. POMS questionnaires use a list of questions that include adjectives describing participants' current mood states. The questions use a five-point Likert scale (Likert, 1932) with the following response options: not at all, a little, moderately, quite a lot, and extremely. Most answers are encoded as integer values from 0 to 4, with a few exceptions encoded from 4 to 0. The Czech version includes 37 questions. From the bottom up, individual questions are aggregated into six dimensions of mood states corresponding to six factors: anger-hostility, fatigue-inertia, vigor-activity, depression-dejection, confusion-bewilderment, and tension-anxiety. Spielberger (1972) states that POMS is unique in providing measures of vigor-activity, fatigue-inertia, and confusion-bewilderment. In the following text, we refer to the factors only by their initial terms, i.e., vigor. The factors aggregate into the Total Mood Disturbance (TMD) score.

Total Mood Disturbance is calculated as the sum of partial scores for all factors. A higher TMD score indicates a higher level of mood disturbance; in other words, the higher the number, the worse the mood. Formula 1 presents the equation.

$$TMD = (anger + fatigue + depression + confusion + tension) - vigor \quad (1)$$

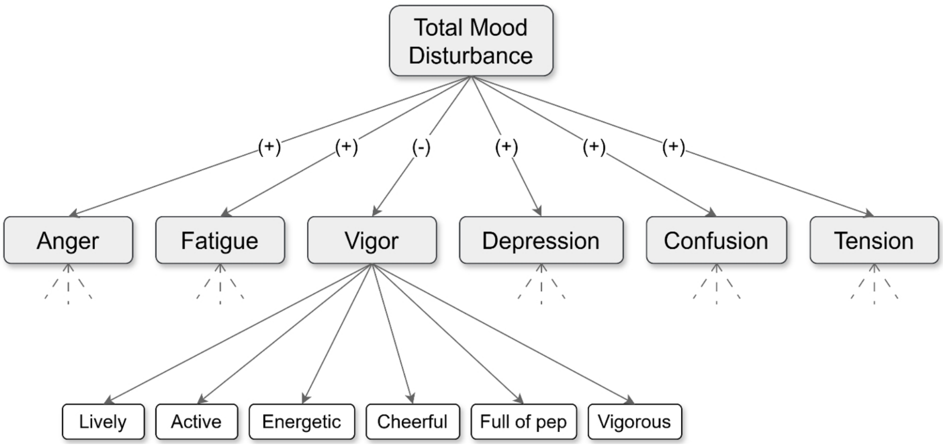

Figure 1: Total Mood Disturbance, factors, and questions (adjectives) for vigor. Source: own.

TMD is calculated by adding the partial scores for tension, depression, anger, fatigue, and confusion and then subtracting the partial score for vigor (McNair et al., 1971). Most factors represent mood disturbance and add to the score, whereas vigor represents mood improvement and is therefore subtracted. A constant of 100 is added to the TMD score to eliminate negative scores (Sahli et al., 2020). Individual factors are calculated according to the scoring instructions and weights for POMS (McNair et al., 1971). The Czech version of POMS uses the same calculations for TMD and factors as the original version described above. However, the weights of individual questions have been adapted for Czech respondents. For details, see Stuchlíková et al. (2005). For the seminars, we used the Czech version of POMS because the target group for this research was students enrolled in Czech study programs. The seminars included both physical and mental activities. Relevant studies state that physical activity positively correlates with improvements in participants' mental health (Berger and Motl, 2000; White et al., 2017). POMS is therefore a suitable psychological method for evaluating teamwork during project management games.

POMS Online

To conduct our research, we used POMS Online (Kunhart, 2025). POMS Online is a software solution that implements the POMS method. This solution builds on the ad hoc prototype that we used in 2023/24. The solution supports questionnaire management, data collection, and data export for data analysis. POMS Online consists of a back-end application and a front-end application, which communicate via a standard REST[1] API[2]. The back-end application supports administration and database functions. The front-end application is used for data collection via forms. Figure 2 displays the entity model of the software solution.

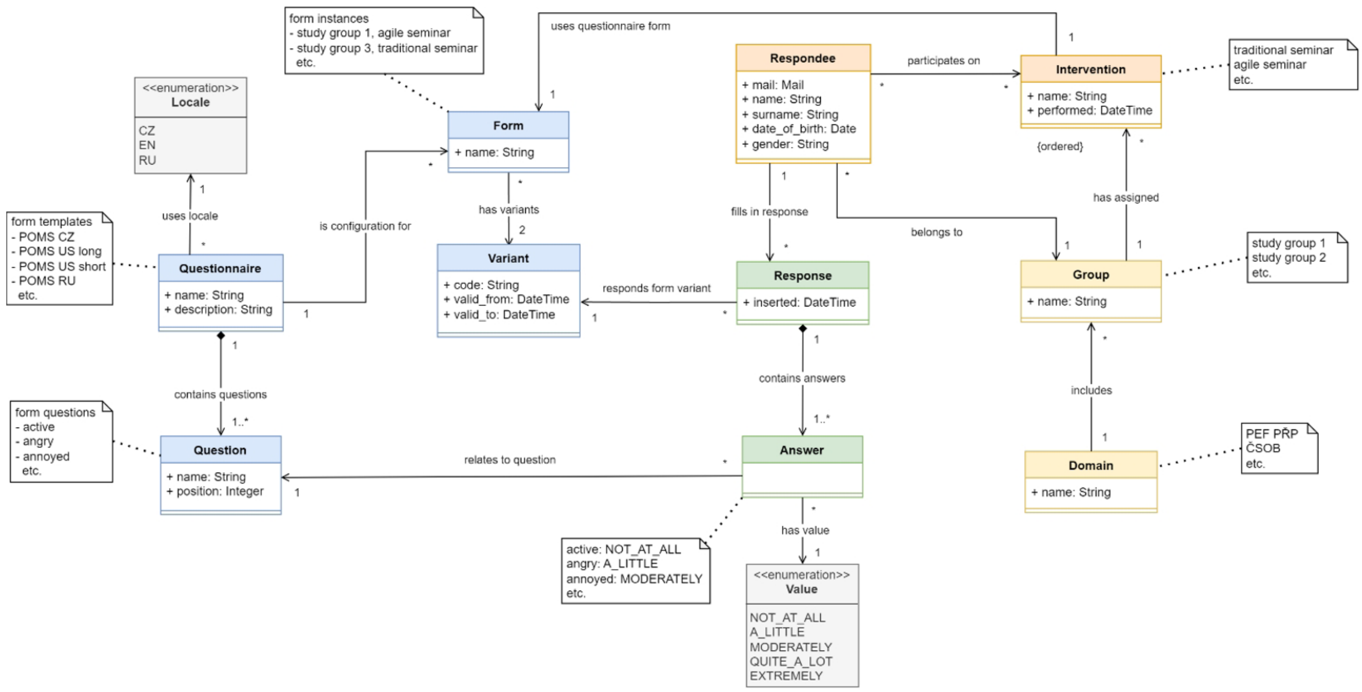

Figure 2: Entity model for POMS Online application. Source: Kunhart (2025).

1 Representational State Transfer.

2 Application Programming Interface.

The entity model can be divided into three primary areas:

- Back-office entities (yellow and orange).
- Questionnaire entities (blue).
- Response entities (green).

Back-office entities are used for research management, i.e., defining domains, research groups, and interventions. Questionnaire entities are used to define POMS questionnaires, i.e., the Czech version of POMS, and to prepare concrete forms. Response entities represent concrete responses and answers completed by participants. To complete the form, each participant first enters a code that is unique to the given form and its variant. The code is provided by the research coordinator. After the code is verified, the participant answers the questions valid for the form, and the response is saved to the database. For further details about the implementation and user interface of the POMS Online solution, please refer to Kunhart (2025).

Practical project management seminars

We organized two new pairs of practical project management seminars in 2024 and 2025. For the purposes of this research, we define "seminars" as sets of lessons for multiple study groups of students on the same topic, i.e., the waterfall or agile approach, organized over a two-week period under similar working conditions. The practical seminars form an integral part of the Planning and Project Management course at the Faculty of Economics and Management of the Czech University of Life Sciences Prague, which takes place in the fall semester. We therefore conducted the survey in November and December. Each year, we organized one waterfall seminar and one agile seminar and evaluated students' teamwork in both approaches. Each approach is better suited to distinct types of projects and involves different kinds of interaction and emotional states within teams. We used serious management games for the seminars, and the activities included both physical activities and soft-skills practice. For most students, the seminars represented their first practical project management experience. In both seminars, students worked in the same project teams of 4–6 members.

In the first seminar, the management game involved building a model of a medieval castle using the waterfall approach. The main goal of the management game was to build a representative castle for the Czech king, and students were presented with a list of functional and non-functional requirements, such as "at least two towers" and "indomitable walls". Each team selected a project manager and prepared a project plan in advance, including a work breakdown structure with all tasks and estimates. Once construction had begun, the team could no longer change the plan. Students used tools such as paper, scissors, crayons, and wooden skewers to build the castle. They spent approximately 15 minutes planning and 60 minutes building. In the second seminar, the management game involved building an amusement park from LEGO components using a simplified Scrum method. In this seminar, we did not define precise requirements in order to support creativity and innovation. Instead, we presented students with real-world examples as inspiration. Students frequently added new user stories for innovative ideas that emerged during the game. Each team selected a Product Owner and a Scrum Master, prepared a short initial Product Backlog, and worked in Sprints. Due to limited seminar time, we used a simplified version of Scrum that merged all events, i.e., Planning, Review, and Demo. Students spent approximately 10 minutes preparing the initial backlog and 65 minutes building. The teams completed 3–4 Sprints during the seminar. We used the remaining 15 minutes of both seminars for instructions, questionnaires, and presentations of castles and amusement parks to other teams.

Questionnaire survey design

We prepared a pair of questionnaires for each seminar to evaluate changes in students' mood states during the management games and between waterfall and agile seminars. We used the POMS Online solution to set up the questionnaires. At the beginning of each seminar, we introduced the students to the management game and the purpose of our research, which is to continuously improve the quality of project management teaching and practical seminars. The students filled out the first questionnaire form (variant A) after the introduction, before the start of the management game, and the second questionnaire form (variant B) after it ended. The questionnaire forms used the Czech version of POMS and contain 37 questions with Czech adjectives. We named each form accordingly, e.g., waterfall seminar, 18. November 2025, 2:00 PM, form variant A, and published it for a limited time that matched the seminar schedule. We used online forms in POMS Online for the questionnaires and QR[3] codes to deliver the questionnaires to the students. In the survey, we collected students' university e-mail addresses and their responses. E-mail addresses are required because they serve as unique identifiers that link responses between form variants and seminars. We did not collect any other personal information.

Data processing and analysis

We collected quantitative primary data through the questionnaire forms in POMS Online front-end versions 1.1.0 and 1.2.0. After completing all the seminars, we processed the data. Data processing and analysis involved three steps: data collection, data transformations, and statistical analysis (see Figure 3). We used POMS Online back-end 2.0.1 to save form data. We used the Forms module in POMS Online to export the data. We exported one dataset for responses in 2024, and one dataset for responses in 2025. The exported data in CSV[4] format includes all answers, calculated factor scores, and calculated TMD scores. Data transformations include data fixes, cleanup, and anonymization. In data fixes, we reviewed e-mail addresses, converted them to lowercase, and fixed typos such as mismatched letters or e-mail domains that could have prevented correct pairing of the responses between variants and seminars. During data cleanup, we removed ineligible records. In order to compare the changes in respondents' mood states between the variants and the seminars, we required them to complete four questionnaire forms (two form variants for

3 Quick Response.

4 Comma-Separated Values.

two seminar types). Therefore, we removed respondents with fewer than four responses. Finally, we anonymized all e-mail addresses using one-way hash. We performed data fixes, cleanup, and transformations in Excel and Python 3.14.

Figure 3: Steps for questionnaire data collection and statistical analysis. Source: own.

We used the datasets in CSV format for statistical analysis. First, we confirmed that the datasets conformed to a normal distribution to allow hypothesis testing. For normality confirmation, we used the normaltest function from SciPy and visually checked the distribution of the data. To maintain consistency with our prior research methodology, we tested the hypotheses formulated in the research objectives using a two-sided Wilcoxon signed-rank test for the difference between two paired data samples (Wilcoxon, 1945). In our prior research, we selected this non-parametric test due to small sample size and slight skewness. Although the current dataset contains a substantially increased number of observations and exhibits normal distribution characteristics suitable for parametric tests, we retained the Wilcoxon test to ensure methodological consistency between our prior and current studies. We used the wilcoxon function from SciPy for the statistical tests and set the same significance threshold of 0.05. For statistical analysis, we used Python 3.14 and the Jupyter ecosystem, including Jupyter core 5.9.1, pandas 3.0.1, NumPy 2.4.3, and SciPy 1.17.1.

RESULTS

In the current research, we collected data from 2024–2025. In 2024, we collected data from 139 eligible respondents, and in 2025, we collected data from 98 eligible respondents. Each eligible respondent completed four questionnaire forms, as described in the methods. We therefore collected 556 distinct records in 2024 and 392 records in 2025. Each record includes factor scores and TMD scores, which were necessary for further calculations and statistical tests.

Total mood improvement during seminars

First, we evaluated changes in participants' mood states during waterfall and agile seminars. For this evaluation, we compared TMD scores between the start of the management game (variant A) and after its end (variant B). A lower TMD indicates better mood and vice versa. Thus, a decrease in TMD score indicates an improvement in participants' mood, whereas an increase indicates deterioration. Table 1 presents descriptive statistics for TMD scores in 2024. The table displays the sample size for 2024 (n_{24} = 139), mean, standard deviation, variance, and minimum and maximum values for each seminar type and variant. Mean values decreased for both seminar types, indicating a total mood improvement among participants in both cases. For waterfall seminars, the mean value decreased from 132.55 to 127.31 during the seminars, and for agile seminars, the mean value decreased from 126.59 to 123.73. Both changes were associated with increases in standard deviation and variance. In addition, scores for waterfall seminars were higher for both variants, indicating a worse mood state of participants both before and after the management game. The most extreme values were associated with agile seminars and variant B.

2024		*n*	mean	std dev	var	min	max
Waterfall seminars	Variant A	139	132.55	13.52	184.15	112	192
	Variant B	139	127.31	18.14	331.55	106	212
Agile seminars	Variant A	139	126.59	16.04	259.03	100	198
	Variant B	139	123.73	18.17	332.72	100	228

Table 1: Descriptive statistics for TMD scores in 2024. Source: own.

Table 2 presents descriptive statistics for TMD scores in 2025. The table displays the sample size for 2025 (n_{25} = 98), mean, standard deviation, variance, and minimum and maximum values for each seminar type and variant. Similarly to 2024, mean values decreased for both seminar types, indicating total mood improvement among participants in both cases. For waterfall seminars, the mean value decreased from 138.99 to 132.76 during the seminars, and for agile seminars, the mean value decreased from 131.13 to 127.27. Both changes were associated with increases in standard deviation and variance, although the increase was lower than in 2024. Scores for waterfall seminars were higher for both variants, indicating a worse mood state of participants both before and after the management game. The lowest scores were associated with agile seminars, whereas the highest score was associated with waterfall seminars and variant B. Complete descriptive statistics are provided in Tables 1 and 2.

2025		*n*	mean	std dev	var	min	max
Waterfall seminars	Variant A	98	138.99	17.89	323.29	108	190
	Variant B	98	132.76	19.54	385.75	105	214
Agile seminars	Variant A	98	131.13	17.94	325.00	100	181
	Variant B	98	127.27	18.09	330.57	100	184

Table 2: Descriptive statistics for TMD scores in 2025. Source: own.

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For a visual comparison between both years, see Figure 4. In the chart, the *x*-axis represents seminars, and the y-axis represents TMD scores. The bars represent TMD scores for a given year and seminar type, whereas the error bars represent the standard deviations for these TMD scores.

We tested the first two hypotheses, H1 and H2, to determine whether participants' total mood improved significantly during the seminars. H1 covered the waterfall seminars, and H2 covered the agile seminars. For H1, which concerned waterfall seminars, we found statistically significant differences in TMD scores for both 2024 and 2025, with *p*-values lower than 0.001. Both *p*-values were below the threshold of 0.05, confirming $H1_1$ for both years. For H2, which concerned agile seminars, we also found statistically significant differences in TMD scores for both 2024 and 2025, with *p*-values of <0.001 and 0.0041. Both p-values were below the threshold of 0.05, confirming $H2_1$ for both years. Table 3 provides complete test statistics and details.

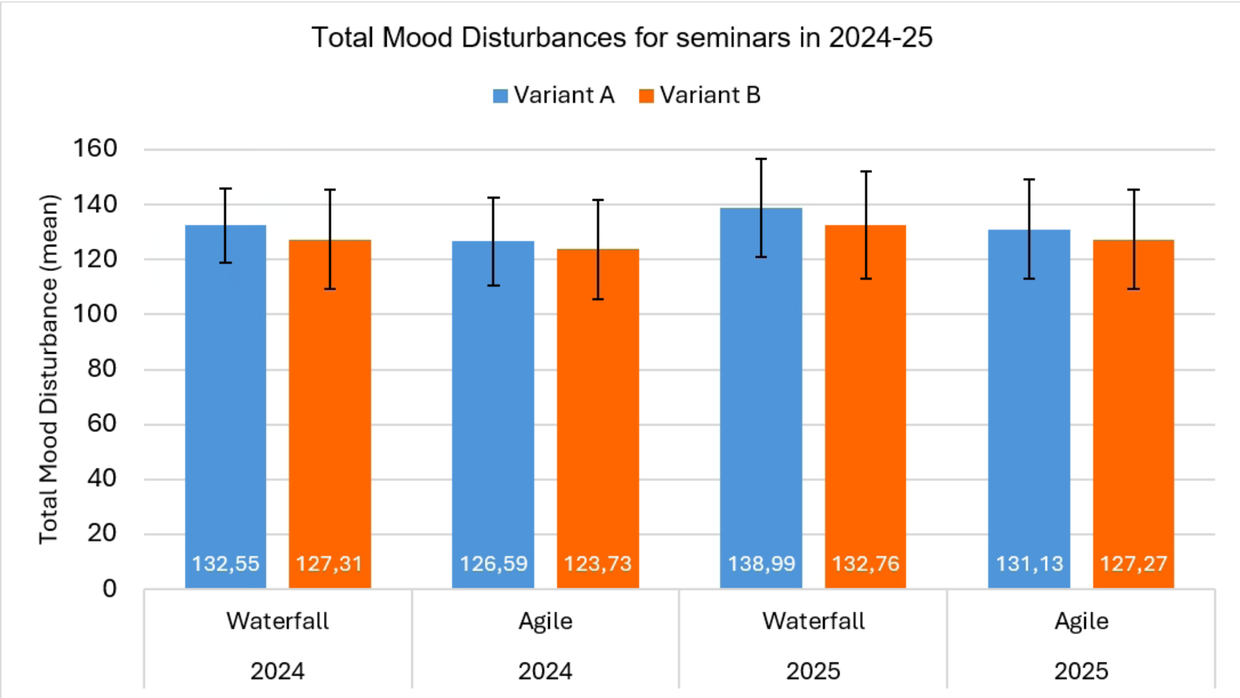

Figure 4: TMD scores for all seminars in 2024-25. Source: own.

2024-25		hypothesis	statistic	*p*-value	confirmed
Waterfall seminars	2024	$H1_1$	1777.5	< 0.001	yes
	2025		1155.5	< 0.001	yes
Agile seminars	2024	$H2_1$	2513.0	< 0.001	yes
	2025		1367.5	0.0041	yes

Table 3: Statistical test results for total mood change between variants A and B in 2024 and 2025. Source: own.

Based on the results of testing hypotheses H1 and H2, we can answer RQ1 as follows: participants' total mood improved during both waterfall and agile project management seminars. The results indicate that practical project management seminars and management games have a positive effect on participants' mood.

Individual factor improvements

Next, we analysed changes in all individual factors during the seminars: anger, fatigue, vigor, depression, confusion, and tension. In the analysis, we compared individual factor scores between variants A and B of the questionnaires. For all factors except vigor, a decrease in score indicates an improvement in the factor and vice versa. For example, a lower anger score indicates lower participant anger during the seminar. For vigor, however, this logic is reversed. A decrease in vigor score indicates deterioration in participants' energy during the seminar. Lower overall scores for anger, confusion, depression, and tension correspond to a smaller number of questions contributing to these scores than for fatigue and vigor. Figures 5 and 6 present factor scores (means) for waterfall and agile seminars in 2024. In the charts, the x-axis represents the six factors, and the y-axis represents factor scores. During waterfall seminars, all factors improved (vigor increased, while the other factors decreased). During agile seminars, all factors except anger improved; anger worsened only slightly. Both charts provide visual details. Descriptive statistics for all factors in 2024 are available in Table 10 in Appendix B and include the sample size (n_{24} = 139), standard deviation, variance, and minimum and maximum scores.

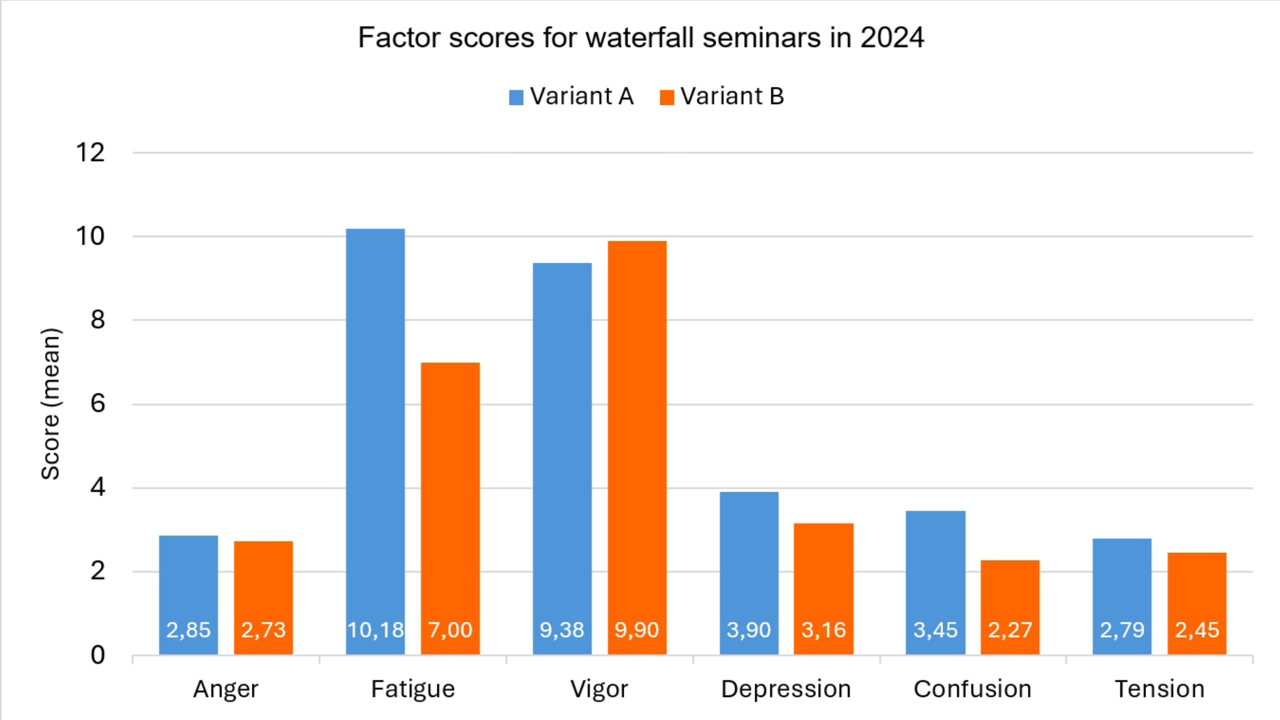

Figure 5: Factor scores for waterfall seminars in 2024. Source: own.

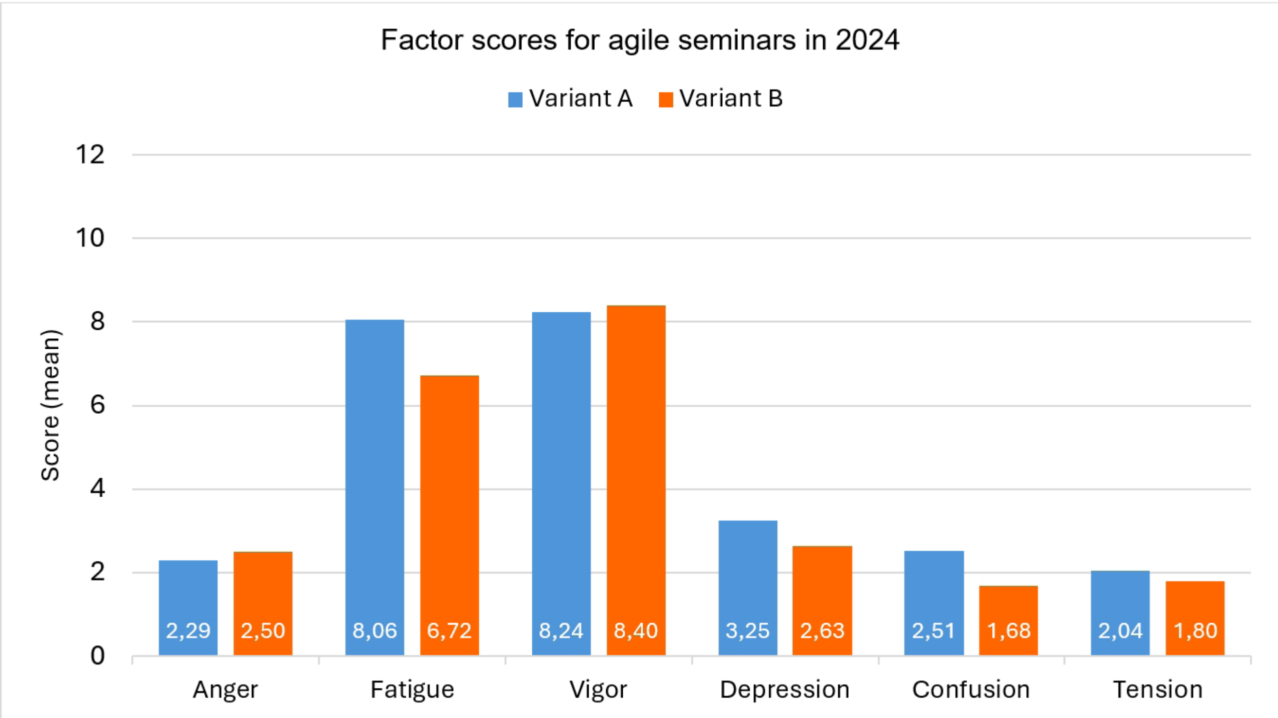

Figure 6: Factor scores for agile seminars in 2024. Source: own.

Figures 7 and 8 present factor scores (means) for waterfall and agile seminars in 2025. The charts present information similar to that for 2024, with the x-axis representing the six factors and the y-axis representing factor scores. During waterfall seminars, most factors improved, with only vigor worsening slightly. During agile seminars, all factors improved. Both charts provide visual details. Descriptive statistics for all factors in 2025 are available in Table 11 in Appendix B and include the sample size ($n_{25} = 98$), standard deviation, variance, and minimum and maximum scores.

In hypotheses H3 and H4, we tested whether the changes and improvements described above and visualized in Figures 5–8 were significant. In H3, we tested all six factors during the waterfall seminars, and in H4, we tested all six factors during the agile seminars. For 2024, we found statistically significant differences in factor scores for both waterfall and

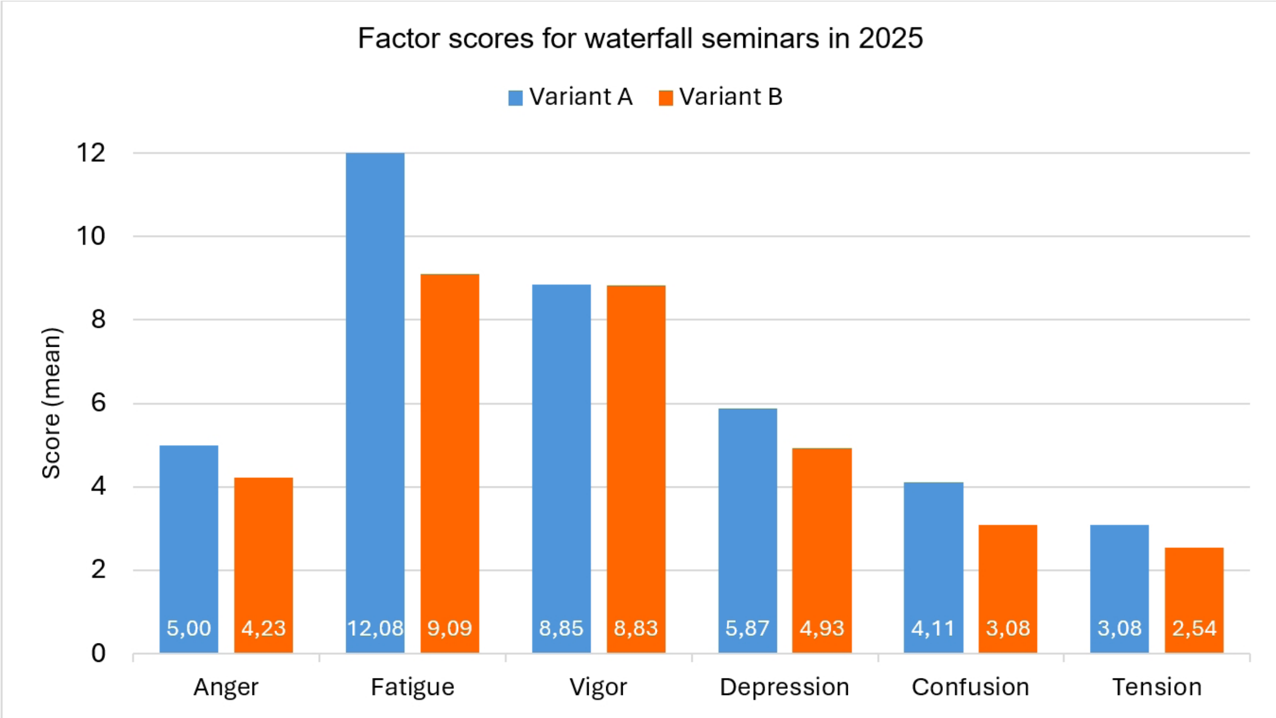

Figure 7: Factor scores for waterfall seminars in 2025. Source: own.

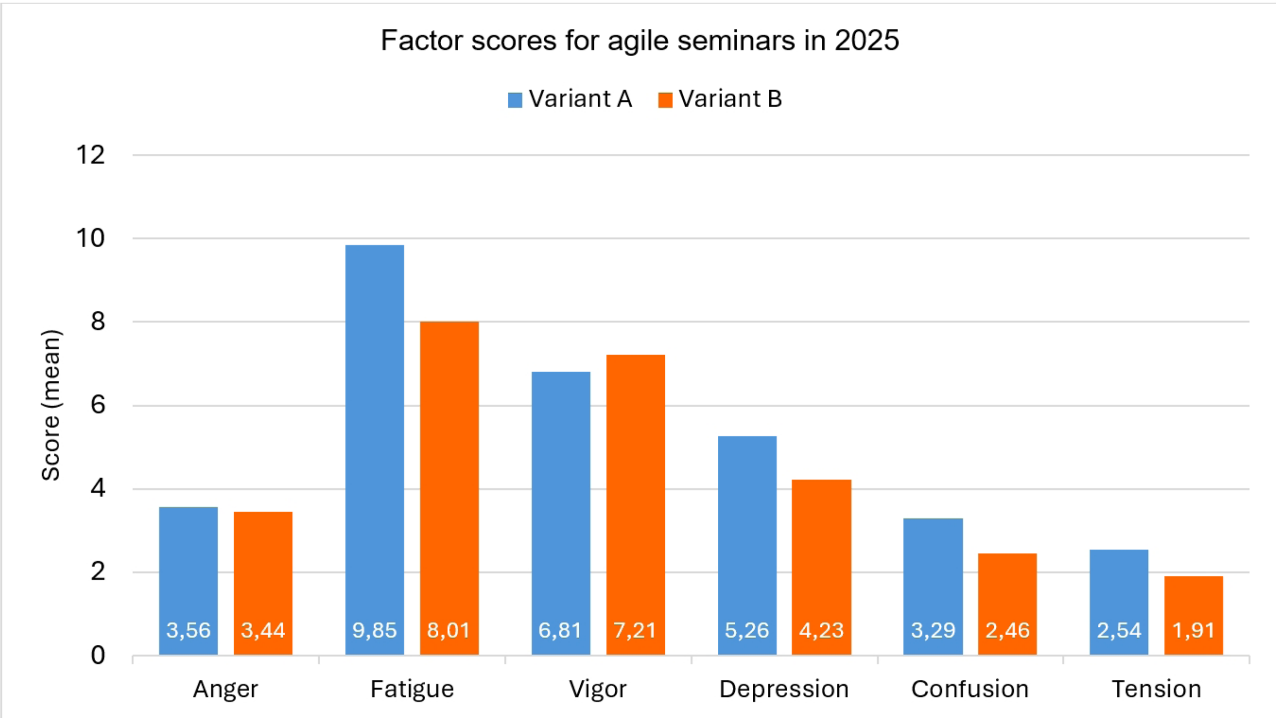

Figure 8: Factor scores for agile seminars in 2025. Source: own.

agile seminars. For H3 and the waterfall seminars, the changes in fatigue, depression, confusion, and tension were significant. The *p*-values of <0.001 for these four factors were below the threshold of 0.05, confirming $H3_1$ for these factors. The changes in anger and vigor were not significant, rejecting $H3_1$ for these two factors. For H4 and the agile seminars, the changes in fatigue, depression, and confusion were significant. The *p*-values of <0.001 for these three factors were below the threshold of 0.05, confirming $H4_1$ for these factors. The changes in anger, vigor, and tension were not significant, rejecting $H4_1$ for these three factors. Further details for 2024 are presented in Table 4.

2024	factor	hypothesis	statistic	*p*-value	confirmed
Waterfall seminars	Anger	$H3_1$	1765.0	0.1432	**no**
	Fatigue		1230.5	< 0.001	yes
	Vigor		3769.0	0.3918	**no**
	Depression		1729.0	< 0.001	yes
	Confusion		1373.0	< 0.001	yes
	Tension		2150.0	< 0.001	yes
Agile seminars	Anger	$H4_1$	1811.5	0.7985	**no**
	Fatigue		2988.5	< 0.001	yes
	Vigor		2988.5	0.6095	**no**
	Depression		1305.0	< 0.001	yes
	Confusion		1077.0	< 0.001	yes
	Tension		1760.5	0.1001	**no**

Table 4: Statistical test results for factor changes between variants A and B in 2024. Source: own.

For 2025, we also found significant differences in factor scores for both seminar types. For H3 and the waterfall seminars, the changes in fatigue, depression, confusion, and tension were significant. The *p*-values of <0.001 for fatigue and confusion, 0.0098 for depression, and 0.0244 for tension were below the threshold of 0.05, confirming $H3_1$ for these factors. The changes in anger and vigor were not significant, rejecting $H3_1$ for these two factors. For H4 and the agile seminars, the changes in fatigue, depression, confusion, and tension were significant. The *p*-values of <0.001 for fatigue and confusion, 0.0248 for depression, and 0.0480 for tension were below the threshold of 0.05, confirming $H4_1$ for these factors. The changes in anger and vigor were not significant, rejecting $H4_1$ for these two factors. Further details for 2025 are presented in Table 5.

2025	factor	hypothesis	statistic	*p*-value	confirmed
Waterfall seminars	Anger	$H3_1$	1354.5	0.2010	**no**
	Fatigue		835.5	< 0.001	yes
	Vigor		1868.0	0.5809	**no**
	Depression		1113.5	0.0098	yes
	Confusion		791.5	< 0.001	yes
	Tension		1187.5	0.0244	yes
Agile seminars	Anger	$H4_1$	1001.5	0.9643	**no**
	Fatigue		1020.0	< 0.001	yes
	Vigor		1655.0	0.5605	**no**
	Depression		915.5	0.0248	yes
	Confusion		600.0	< 0.001	yes
	Tension		799.0	0.0480	yes

Table 5: Statistical test results for factor changes between variants A and B in 2025. Source: own.

Based on the results of testing hypotheses H3 and H4, we can answer RQ2 as follows: most factors improved significantly during the practical project management seminars. Specifically, fatigue, depression, and confusion improved in both years and both seminar types.

DISCUSSION

We confirmed that participants' total mood and most individual factors improved during the seminars for both seminar types and all eligible years. These results indicate that our practical project management seminars had a positive effect on participants' mood, teamwork, and soft-skills practice. We compare all results and findings from the current research with the results of our prior research, discuss minor differences in seminar design between years, and address the limitations and implications of the research. Specifically, we compare results from our prior research using 2023 data ($n_{23} = 49$) with results from the current research using 2024 data ($n_{24} = 139$) and 2025 data ($n_{25} = 98$). Because our prior paper discussed the broader literature in detail, the present discussion focuses primarily on comparison across years, followed by a concise validation against related research.

Total mood changes during seminars

First, we discuss total mood changes during waterfall seminars. Figure 9 shows TMD scores during waterfall seminars for the years 2023–2025, in which we conducted the research. In the chart, the x-axis represents years, and the y-axis represents TMD scores. The bars represent TMD scores for the given years and seminar types, whereas the error bars represent the standard deviations for these scores. The chart shows that participants' total mood improved each year. The changes displayed in the chart are positive, which is why we refer to them as total mood improvements in the Results section. The resulting scores for waterfall seminars also show that participants' initial mood started with a worse score and ended with a worse score than in the preceding year. For example, in 2023, the TMD score started at 121.50 and improved to 111.90. Higher initial TMD scores correspond to poorer student mood states before the start of the seminars and management games.

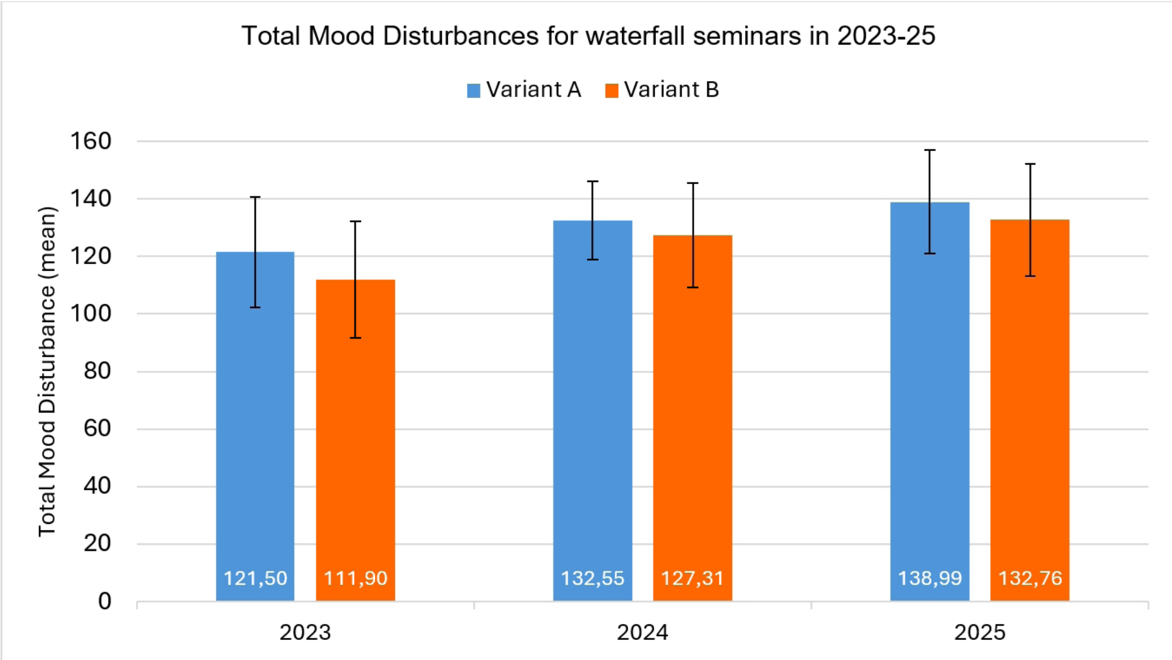

Figure 9: TMD scores for waterfall seminars in 2023-25. Source: own.

Second, we discuss total mood changes during agile seminars. Figure 10 shows TMD scores during agile seminars for the years 2023–2025. The chart presents TMD scores for these seminars. Changes in participants' mood states are positive for all three years, which is consistent with waterfall seminars. However, differences are also visible. The initial TMD scores are nearly equal for 2023 (127.00) and 2024 (126.59) and slightly higher in 2025 (131.13). The final TMD scores indicate differences between years similar to those observed for the waterfall seminars, i.e., the score is several points worse than in the previous year while still showing improvement. We also observed a larger improvement in 2023 (from 127.00 to 115.70), which may be related to the lower number of eligible participants in 2023 (n_{23} = 49) or to the change in the theme of agile management games from robots to amusement parks between 2023 and 2024.

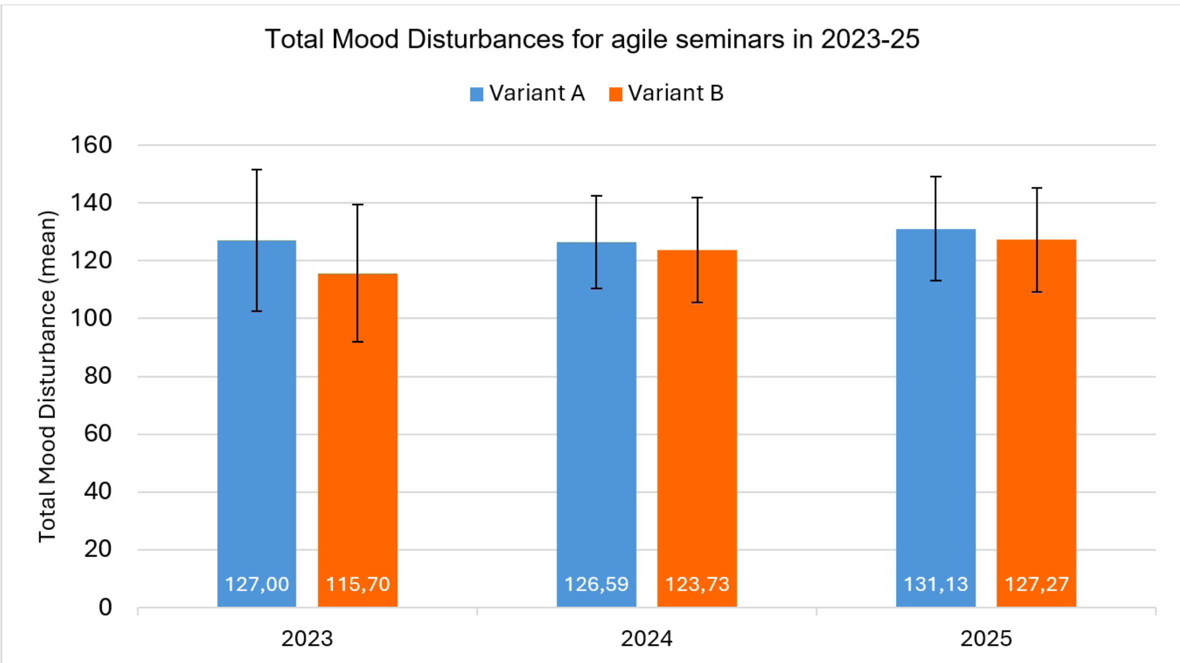

Figure 10: TMD scores for agile seminars in 2023–2025. Source: own.

Third, we discuss characteristics and hypotheses shared by both seminar types. The standard deviations are generally lower for both seminar types in 2024 and 2025 than in 2023. Lower standard deviations indicate more consistent responses in the current years than in 2023. This difference may relate to the smaller data sample ($n_{23} = 49$) in 2023. Details are provided in Table 6.

		2023	2024	2025
Waterfall seminars	Variant A	19.12	13.52	17.89
	Variant B	20.33	18.14	19.54
Agile seminars	Variant A	24.52	16.04	17.94
	Variant B	23.78	18.17	18.09

Table 6: Comparison of Total Mood Disturbance standard deviations in 2023-25. Source: own.

From a statistical perspective, all described total mood improvements are statistically significant, as confirmed by hypotheses H1 and H2. Table 7 summarizes the hypothesis results, showing that both hypotheses were confirmed for both seminar types and all eligible years.

Based on this comparison of results, we can answer the final research question (RQ3): the results of participants' total mood improvement are consistent across the years 2023–2025, in which we conducted the seminars. Hence, our new findings and results from 2024–2025 fully support and reinforce our original findings from 2023.

	hypothesis	2023	2024	2025
Waterfall seminars	H1	confirmed	confirmed	confirmed
Agile seminars	H2	confirmed	confirmed	confirmed

Table 7: Comparison of the results of hypotheses H1 and H2.

Individual factor changes

Considering the factors, we examined only vigor and fatigue in prior research. We extended this investigation to all six factors in the current research using data from 2024 and 2025. For this reason, we can compare the results for vigor and fatigue across all years, whereas the remaining four factors can be compared only between 2024 and 2025. Table 8 compares the results of hypotheses $H3_1$ for waterfall seminars and $H4_1$ for agile seminars. Hypotheses $H3_1$ and $H4_1$ relate to individual factor improvements, which we tested separately for each factor. The table presents *p*-values for all individual factors and eligible years. Default color values indicate confirmed hypotheses, whereas bold values indicate rejected hypotheses.

2023-25	factor	hypothesis	2023	2024	2025
Waterfall seminars	Anger	$H3_1$	-	**0.1432**	**0.2010**
	Fatigue		<0.001	< 0.001	< 0.001
	Vigor		**0.6021**	**0.3918**	**0.5809**
	Depression		-	< 0.001	0.0098
	Confusion		-	< 0.001	< 0.001
	Tension		-	< 0.001	0.0244
Agile seminars	Anger	$H4_1$	-	**0.7985**	**0.9643**
	Fatigue		<0.001	< 0.001	< 0.001
	Vigor		0.0140	**0.6095**	**0.5605**
	Depression		-	< 0.001	0.0248
	Confusion		-	< 0.001	< 0.001
	Tension		-	**0.1001**	0.0480

Table 8: Comparison of the results and *p*-values of hypotheses H3 and H4 for individual factor improvements in 2023-25. Source: *own*.

As shown in the table, most factors exhibit consistent results between years. For fatigue, we observed uniform results across all years and seminar types, with *p*-values of <0.001. Hence, all seminars significantly reduced participants' fatigue. For depression and confusion, we also observed consistent results for all combinations, with p-values below the threshold of 0.05. Similar to fatigue, all seminars decreased participants' depression and confusion. For tension, the results are consistent only for the waterfall seminars, with *p*-values below 0.05. The results for agile seminars are ambiguous. In 2024, $H4_1$ was rejected, whereas in 2025, $H4_1$ was confirmed with a *p*-value of 0.0480, which is close to the threshold of 0.05. For anger, we observed consistent results for both years and seminar types, indicating no significant change in participants' anger during the seminars, with *p*-values above 0.05. Finally, for vigor, we observed consistent results except for the agile seminars in 2023. Most vigor results indicate no significant improvement, with p-values greater than 0.05. The exception may have been caused by the limited data sample in 2023. Table 8 presents *p*-values for all factors.

Validation in related research

Studies using the Profile of Mood States demonstrate that physical activity positively influences mood changes (Berger and Motl, 2000). Multiple studies support this relationship. White et al. (2017) describe that practicing physical exercise is associated with improvements in mental health and mood, which is similar to our research outcomes. Results by Sahli et al. (2020) on soccer players also suggest that physical training positively influences students' physiological responses and creates positive psychological states. The impact of physical activity on mood is heightened by verbal encouragement from the teacher. Our findings extend these results to project management education, where practical seminars incorporating physical activities demonstrated positive effects on participant mood. Specifically, our results show improvements in soft-skills development and teamwork experience, consistent with this broader literature. Consistent with our outcomes, Reigal et al. (2021) demonstrated that moderate physical activity predicts better mood states and lower anxiety than vigorous activity, suggesting that our moderate-intensity management game approach aligns with optimal mood-enhancing parameters. Engaging in management games lowers participants' mood disturbance as well as fatigue and increases their total mood. Our results correspond to previous research by De Gloria et al. (2014) and Hellström et al. (2023), which shows that serious management games have positive motivational outcomes and offer convenient practical experience. Jaccard et al. (2022) demonstrated through a 10-year qualitative analysis that serious games trigger active pedagogies, develop soft-skill competencies, and transform teacher-student relationships.

The effectiveness of our approach is validated by comparable educational interventions using LEGO-based simulations. In a study by Paasivaara et al. (2014), students learned basic Scrum concepts using a LEGO-based simulation game, with participants reporting general satisfaction and significant learning outcomes. Barcelos Bica and Gouvea da Silva (2020) conducted a similar management game using LEGO blocks to build cities and concluded that students considered this activity highly effective and practical for learning Scrum. Both studies used an approach comparable to our agile seminars, in which participants constructed robots from LEGO components. The outcomes of both referenced papers correspond to the improvement in participants' total mood and vigor observed in our seminars, where improved vigor signifies higher energy, activity, and satisfaction. The importance of mood measurement extends beyond educational contexts. Pang et al. (2023) demonstrated through POMS measurement that positive mood profiles were associated with improved athletic performance, reinforcing the need to consider mood across diverse domains. In addition, Havazík and Pavlíčková (2020) found that the Scrum-based agile game helped the majority of students understand basic agile concepts. Miller and Vaca Núnez (2022) designed a management game to experience differences between waterfall and agile approaches and identified comparable imbalances in both methodologies. While traditional approaches emphasize extensive planning with fewer decisions, agile methods allow for faster initiation and more decisions throughout the game. Despite these differences, both seminar types showed comparable improvements in mood, demonstrating that management games are effective across different teaching approaches. Rumeser and Emsley (2019) identified design principles supporting cross-contextual effectiveness, while Kesti et al. (2022) confirmed benefits across diverse settings. The research consistently supports the value of serious management games in learning contexts.

Practical implications and limitations

We maintained similar project requirements and working conditions for the practical seminars and management games between years to ensure research consistency. We made minor changes to the practical seminars as part of their continuous improvement. Since 2024, students have been building amusement parks instead of robots in agile seminars. The robot theme was a one-time event in 2023 and is no longer relevant. This change may have led to lower TMD scores for agile seminars, as discussed above. However, this difference could also be related to the limited data in the 2023 pilot research, since the results from 2024 and 2025 are consistent in this respect. Next year, we may either introduce a new topic or return to robots and observe the differences. We also simplified auxiliary work in the seminars, such as tracking work progress, to focus more on practical teamwork and soft skills. Regarding the research design, we no longer work with study groups. Study groups are not required for any research questions or comparisons between years.

Two main limitations of our research relate to the nature of the practical seminars and the scheduling of teaching at the faculty. First, we used two different management games for waterfall and agile seminars because students practise a different project management approach in each seminar type. Each approach involves different teamwork models, interactions, and skills. Second, to compare students' mood states during and between seminars, we required them to complete four questionnaires. We therefore had to eliminate all participants with fewer than four completed questionnaires from the datasets during data transformation. This requirement limited the questionnaire return rate. The return rate was therefore negatively affected by student absences, holidays, and various university events. In 2023, we arranged a limited study and collected data from 49 participants (a 49.5% return rate for eligible seminars). In 2024 and 2025, we extended our research to all students in the subject. In 2024, we collected data from 139 participants (a 51% return rate for all seminars). However, in 2025, we collected data from only 98 participants (a 30% return rate) because nearly half of the practical seminars were held on public or university holidays. Moreover, moving seminars to other weekdays is not an option because of other subjects that students attend. On the other hand, we addressed all limitations and suggestions for future research described in our previous research: we conducted a more detailed analysis of the factors, improved the seminars based on the results, and implemented a comprehensive software solution to support research design and data collection.

CONCLUSION

In 2023–2025, we organized practical waterfall and agile project management seminars each year for students in a project management course using serious management games. We collected quantitative data on participants' mood states based on the Czech version of POMS. Our results for total mood improvement and for fatigue, depression, and confusion indicate a high level of consistency between years. We therefore verified and reinforced our previous findings regarding total mood improvement and fulfilled our research goal. In future research, we could extend this work to include diverse study groups and datasets beyond students at a single university in one project management subject and compare findings across these areas. We can focus on students at other universities, different languages, or employees training in professional courses. We expect further development of the POMS Online software solution to better support multiple questionnaire types in different languages, which is essential for expanding the research. We could also integrate statistical functions in Python into the solution and introduce new functions.

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APPENDIX

APPENDIX A LIST OF PROFILE OF MOOD STATES ADJECTIVES (QUESTIONS)

Czech adjectives are not always exact translations of the original terms. For several adjectives, the authors selected and attested more suitable Czech alternatives.

Question identifier	Czech adjective (question)	English adjective (question)
1	Napjatý	Tense
2	Vzteklý	Angry
3	Opotřebovaný	Worn out
4	Nešťastný	Unhappy
5	Plný života	Lively
6	Zmatený	Confused
7	Nevrlý	Grumpy
8	Smutný	Sad
9	Energický	Energetic
10	Rozrušený	On edge
11	Naštvaný	Grouchy
12	Sklíčený	Ashamed
13	Rázný	Active
14	Bez naděje	Hopeless
15	Nepříjemný	Uneasy
16	Neklidný	Restless
17	Neschopen se soustředit	Unconcentrated
18	Unavený	Fatigued
19	Rozzlobený	Annoyed
20	Malomyslný	Discouraged
21	Podrážděný	Resentful
22	Nervózní	Nervous
23	Mizerný	Miserable
24	Veselý	Cheerful
25	Rozhořčený	Bitter
26	Vyčerpaný	Exhausted
27	Úzkostný	Anxious
28	Zoufalý	Helpless
29	Utahaný	Weary
30	Popletený	Bewildered
31	Rohněvaný	Furious
32	Plný elánu	Full of pep
33	Zbytečný	Worthless
34	Roztržitý	Forgetful
35	Činorodý	Vigorous
36	Nejistý	Uncertain
37	Přetažený	Bushed

Table 9: List of adjectives in the Czech version of the Profile of Mood States questionnaire. Source: Stuchlíková et al. (2005).

APPENDIX B

2024		factor	*n*	mean	std dev	var	min	max
Waterfall seminars	Variant A	Anger	139	2.8489	3.8082	14.6074	0	24
		Fatigue	139	10.1799	5.4684	30.1196	0	23
		Vigor	139	9.3813	4.6308	21.5999	0	24
		Depression	139	3.8993	3.8911	15.2507	0	18
		Confusion	139	3.4532	2.6586	7.1192	0	14
		Tension	139	2.7914	2.2424	5.0649	0	11
	Variant B	Anger	139	2.7338	4.7613	22.8344	0	24
		Fatigue	139	7.0000	5.9772	35.9855	0	24
		Vigor	139	9.8993	4.8744	23.9318	0	24
		Depression	139	3.1583	5.3095	28.3951	0	28
		Confusion	139	2.2734	3.2093	10.3740	0	16
		Tension	139	2.4460	2.5356	6.4760	0	12
Agile seminars	Variant A	Anger	139	2.2878	3.6742	13.5977	0	18
		Fatigue	139	8.0647	5.8460	34.4233	0	22
		Vigor	139	8.2446	5.3062	28.3600	0	24
		Depression	139	3.4460	4.2361	18.0750	0	23
		Confusion	139	2.5108	2.7520	7.6285	0	11
		Tension	139	2.0360	2.1337	4.5857	0	11
	Variant B	Anger	139	2.5036	4.5223	20.5996	0	24
		Fatigue	139	6.7194	6.2433	39.2613	0	24
		Vigor	139	8.3957	5.4728	30.1684	0	24
		Depression	139	2.6259	4.6693	21.9605	0	28
		Confusion	139	1.6835	2.7564	7.6527	0	16
		Tension	139	1.7986	2.4715	7.6527	0	12

Table 10: Descriptive statistics for individual factor scores between variants A and B in 2024. Source: own.

2025		factor	*n*	mean	std dev	var	min	max
Waterfall seminars	Variant A	Anger	98	5.0000	4.7552	22.8454	0	20
		Fatigue	98	12.0816	5.9310	35.5397	1	24
		Vigor	98	8.8469	4.6541	21.8835	0	20
		Depression	98	5.8673	4.6744	22.0750	0	23
		Confusion	98	4.1122	3.0636	9.4821	0	14
		Tension	98	3.0816	2.5582	6.6118	0	12
	Variant B	Anger	98	4.2857	4.9672	24.9278	0	24
		Fatigue	98	9.0918	6.0695	37.2183	0	24
		Vigor	98	8.8265	4.7359	22.603	0	21
		Depression	98	4.9286	5.3251	28.5412	0	25
		Confusion	98	3.0816	3.1773	10.1995	0	15
		Tension	98	2.5408	2.4751	6.1890	0	12
Agile seminars	Variant A	Anger	98	3.5612	4.5267	20.7024	0	20
		Fatigue	98	9.8469	6.8308	47.1413	0	24
		Vigor	98	6.8163	4.1240	17.1824	0	20
		Depression	98	5.2551	5.0494	25.7590	0	22
		Confusion	98	3.2857	3.0739	9.5464	0	13
		Tension	98	2.3673	2.2830	5.2657	0	9
	Variant B	Anger	98	3.4388	4.4264	19.7952	0	21
		Fatigue	98	8.0102	6.2979	40.0721	0	24
		Vigor	98	7.2143	4.4841	20.3144	0	19
		Depression	98	4.2347	5.0725	25.9959	0	21
		Confusion	98	2.4592	2.9869	9.0138	0	12
		Tension	98	1.9082	2.0308	4.1667	0	9

Table 11: Descriptive statistics for individual factor scores between variants A and B in 2025. Source: own.