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	International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE)
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EDITORIAL

International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE) is an open access international peer-reviewed, open-access journal, which provides a platform for highlighting and discussing various cognitive science issues dealing with the problems of cognition (and its evolution) within some specific subject field - philosophical, psychological, linguistic, mathematical, psychogenetic, pedagogical, ergonomic. Editorial Board strives to provide a possibility for the scientists of different fields to publish the results of their research, technical and theoretical studies. IJCRSEE is multidisciplinary in approach, and will publish a great range of papers: reports of qualitative case studies, quantitative experiments and surveys, mixed method studies, action researches, meta-analyses, discussions of conceptual and methodological issues, etc. IJCRSEE publisher is The Association for the Development of Science, Engineering and Education, Vranje, Serbia. Co-publishers are: University Business Academy, Faculty of Economics and Engineering Management in Novi Sad, Serbia, Faculty of Education, University of Belgrade, Serbia, Center for Robotics and Artificial Intelligence CRAIE, Belgrade, Serbia and Don State Technical University, Rostov on Don, Russian Federation.

IJCRSEE particularly welcomes articles on the results of scientific research in various fields of cognitive science (psychology, artificial intelligence, linguistics, philosophy and neuroscience) catering for international and multidisciplinary audience. Readers include those in cognitive psychology, special education, education, adult education, educational psychology, school psychology, speech and language, and public policy. IJCRSEE has regular sections: Original Research, Review Articles, Studies and articles, Book Reviews, Case Studies, and is published three times a year. This journal provides an immediate open access to its contents, which makes research results available to the public based on the global exchange of knowledge. The journal also offers access to uncorrected and corrected proofs of articles before they are published.

The main aim of the Journal is to discuss global prospects and innovations concerning major issues of cognitive science, to publish new scientific results of cognitive science research, including the studies of cognitive processes, emotions, perception, memory, thinking, problem solving, planning, education and teaching, language and consciousness study, the results of studying man's cognitive development and the formation of basic cognitive skills in everyday life. The Journal seeks to stimulate the initiation of new research and ideas in cognitive science for the purpose of integration and interaction of international specialists in the development of cognitive science as interdisciplinary knowledge.

The International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE) is an international, peer-reviewed, open access journal that publishes original empirical and theoretical contributions at the intersection of cognitive science, education, psychology, and cultural studies. The journal aims to advance understanding of cognitive processes, learning and teaching, as well as cultural and social dimensions of education and knowledge.

IJCRSEE welcomes interdisciplinary research that explores how cognition, language, culture, media, and technology shape educational practices, learning environments, and identity formation in contemporary societies. By bringing together perspectives from cognitive psychology, pedagogy, linguistics, cultural studies, and related fields, the journal seeks to foster theoretically grounded and methodologically rigorous scholarship with clear implications for educational practice and policy.

The journal publishes:

- Original research articles
- Review articles
- Theoretical and methodological studies
- Case studies and monographic studies
- Book reviews

All submissions must be original, written in English, and are subject to a double-blind peer-review process.

Scope of the Journal

IJCRSEE particularly encourages submissions in, but not limited to, the following thematic areas:

1. Cognitive Science and Psychology

- Cognitive science and cognitive processes (perception, attention, memory, learning, problem solving, planning, inference)
- Cognitive psychology and cognitive neurophysiology
- Cognitive pedagogics and cognitive aspects of teaching and learning
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- Cognitive aspects of the methodology of knowledge

2. Education, Curriculum and Learning Environments

- Cognitive research in education and educational psychology
- Curriculum development and design of learning environments
- Education administration and educational leadership
- Elementary and secondary education
- Innovative pedagogical models and active learning approaches
- Teaching and learning technologies; learning systems platforms
- Educational technology and media education
- Science education and STEM/STEAM-oriented cognitive research

3. Cultural Studies, Media and Identity in Education

- Cultural studies and education
- Cognitive culture studies and cultural cognition
- Media, popular culture and society in educational contexts
- Identity, diversity and culture (class, gender, ethnicity, generation, nation)
- Digital culture and cultural practices in learning and socialization
- Cultural policy and governance in education and science
- Discourse, representation and ideology in educational and media texts

4. Language, Text and Cognitive Technologies

- Text processing and cognitive technologies in education and research
- Natural language understanding and educational applications
- Media and multimodal texts in teaching and learning
- Intelligent tutoring systems and adaptive learning environments

5. Artificial Intelligence, Digitalization and Education

- Artificial intelligence in education and learning analytics
- Cognitive aspects of human–AI interaction in educational settings
- Digital platforms, online learning and hybrid learning environments

- Ethical, cultural and policy implications of AI and digital technologies in education

IJCREE has an international editorial board of eminent experts in their field from Russia, USA, Republic of Macedonia, Germany, Hong Kong, Greece, Serbia, Australia, United Kingdom, USA, Turkey, Nigeria, Bulgaria, Romania, Spain, Italy, Republic of Srpska, Croatia, Kingdom of Saudi Arabia (KSA), India, China, Thailand, Israel, Malaysia, Morocco, Jordan,, Iran... We are confident that IJCREE will attract a great number of editors, eminent scientists in the field. The selection will be based on the activities of the editors and their desire to contribute to the development of the journal.

IJCREE provides a platform for academics and scientists professionals to refer and discuss recent progress in the fields of their interests. Authors are encouraged to contribute articles which are not published or not under review in any other journal.

Each submitted manuscript is evaluated on the following basis: the originality of its contribution to the field of scholarly publishing, the soundness of its theory and methodology, the coherence of its analysis, its availability to readers (grammar and style). Normal turn-around time for the evaluation of manuscripts is one to two months from the date of receipt.

Submission of an original manuscript to the journal will be taken to mean that it represents original work not previously published, that is not being considered elsewhere for publication; that the author is willing to assign the copyright to the journal as per a contract that will be sent to the author just prior to the publication and, if accepted, it will be published in print and online and it will not be published elsewhere in the same form, for commercial purposes, in any language, without the consent of the publisher.

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The requirement for the submission of a paper implies that it has not been published before; that it is not under consideration for publication anywhere else; that its publication has been approved by all co-authors.

When considering submitting an article, the Editors have provided the following criteria to assist authors with preparing their submissions:

Originality – The author should ensure that the manuscript has not been previously published nor is being considered by another journal.

Plagiarism - Content should be properly referenced. Be sure to check the paper for possible accidental plagiarism. Some plagiarism checker websites include: <http://www.ithenticate.com/>, www.antiplagiat.ru, www.grammarly.com, www.plagtracker.com or www.duplchecker.com

Writing – Please write in good English (American or British usage is accepted, but not a mixture of these). For non-native English speakers, and perhaps even for some native English speakers, grammar, spelling, usage, and punctuation of the texts are very important for an effective presentation. Hence, manuscripts are expected to be written in a clear, cogent, and readily understandable by an international readership.

Manuscripts must be submitted online. Electronic submission reduces the editorial processing and reviewing time. As part of the submission process, authors are required to check off their submission compliance with all of the following items, and submissions may be returned to authors who do not adhere to the following guidelines:

The submission has not been previously published or presented to another journal for consideration (or an explanation has been provided in Comments to the Editor).

The submission file is in OpenOffice, Microsoft Word, RTF, or WordPerfect document file format.

Where available, DOIs and URLs for the references have been provided.

The text is single-spaced; uses a 12-point font; employs italics, rather than underlining (except with URL addresses); and all illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end.

The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.

If submitting to a peer-reviewed section of the journal, the instructions in Ensuring a Double Blind Review have been followed.

A manuscript goes through the peer review process. Authors submit manuscripts to Editorial office via the online system. The acknowledgement letter should be sent to the author to confirm the receipt of the manuscript. The Chief Editor first reviews manuscripts. Chief Editor is assisted by Section Editors (could also be Co- or Associated Editors). The Editor assigns a Section Editor to see the manuscript through the complete review process and return it with a recommendation or decision. The manuscript is checked to see if it meets the scope of the Journal and its formal requirements. If it is incorrect or unsuitable, the author should be informed and the manuscript filed (or returned if requested) – direct rejection. Manuscripts that are not suitable for publication in the Journal are rejected. A Rejection letter

is sent to the author stating the reason for rejection. If the manuscript conforms to the aims and scope of the Journal, and formally abides by the Instructions to Authors it is sent out for review. Depending on the type of paper, it could be accepted immediately for publication (invited Editorial, Book review etc) by the Chief Editor.

Check that the manuscript has been written and styled in accordance with the Journal style; that it carries an abstract (if applicable), keywords, correct reference system etc. and check that the correct blinding system has been used. If anything is missing ask the author to complete it before the manuscript is sent out for review.

The manuscript is sent out for review. The reviewer reads and evaluates the manuscript and eventually sends a review report to the Chief Editor. The time for review can be set to 2-6 weeks depending on the discipline (more time is usually given to papers in the humanities and social sciences). Make sure to provide the reviewer with clear instructions for the work, e.g. outlined in the form of a Review report or a number of questions to be considered.

Based on the reviewers' comments the Chief Editor makes a decision to:

- Accept the manuscript without further revision
- Accept after revision
- Ask authors to resubmit
- Reject

An acceptance letter is sent to the author and the final manuscript is forwarded to production. Sometimes, the authors are requested to revise in accordance with reviewers' comments and submit the updated version or their manuscript to the Chief Editor. The time for review can be set to 2-6 weeks depending on the discipline and type of additional data, information or argument required. The authors are requested to make substantial revisions to their manuscripts and resubmit for a new evaluation. A rejection letter is sent to the author and the manuscript is archived. Reviewers might be informed about the decision.

After review a manuscript goes to the Copy Editor who will correct the manuscript concerning the correct referencing system, confirmation with the journal style and layout. When Copy Editor finishes his/her work they send manuscripts to the Layout editor.

Layout Editor is responsible for structuring the original manuscript, including figures and tables, into an article, activating necessary links and preparing the manuscript in the various formats, in our case PDF and HTML format. When Layout Editor finishes his/her job they send manuscripts to Proof Editor.

Proof Editor confirms that the manuscript has gone through all the stages and can be published.

This issue has 17 articles (17 Original researches). Our future plan is to increase the number of quality research papers from all fields of science, engineering and education. The editors seek to publish articles from a wide variety of academic disciplines and substantive fields; they are looking forward to substantial improvement of educational processes and outcomes.

Editor in Chief
Prof. Dr. Lazar Stošić, Senior Research Fellow

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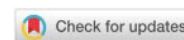
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Perceived Pedagogical Value of Digital Technologies Among Engineering Students

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Abstract: The increasing integration of digital technologies in higher education raises important questions about their real pedagogical value in teaching practice. The aim of this research was to examine students' attitudes about the use of digital technologies, their representation in teaching, and their influence on the perceived pedagogical value of teaching at the technical faculty, examined through correlational and regression analyses. The research also included an analysis of the relationships among digital technologies, student engagement, and students' assessments of teachers' digital competence, particularly under conditions of limited technical resources. The research was conducted on a sample of 375 students in engineering study programs. Data were collected using a structured questionnaire and analysed using exploratory factor analysis, reliability analysis of the measurement scales (Cronbach's alpha and, for the two-item scale, the Spearman-Brown coefficient), correlation analysis and regression models. The results show that, although students generally have a positive perception of digital technologies and teachers' digital competence, exposure to advanced digital tools in teaching remains limited. Student engagement showed as the most significant predictor of the perceived pedagogical value of digital technologies, along with the institutional support and students' digital competencies, which also made significant contributions. In contrast, teachers' digital competence and level of exposure to digital technologies were not significant predictors when considered alongside other variables. These results demonstrate that the perceived pedagogical value of digital technologies primarily depends on the ability to encourage students' interaction and active participation in the teaching process. The research also provides empirical evidence from the technical faculty context and contributes to understanding the conditions under which digital technologies enhance teaching quality.

Keywords: Digital Technologies, Pedagogical Value, Engineering Students, Student Engagement

Introduction

Digital technologies are recognized for their potential to improve learning and encourage new teaching methods. Research shows that using technology in education can lead to better academic performance, increase student motivation, and provide more flexible access to educational resources (Chiu, 2021).

At the same time, while some research points to the benefits that the application of digital technologies in teaching brings, there are also those that point to challenges in their use. Challenges include primarily the insufficient institutional readiness of educational institutions for the use of digital technologies, their inconsistent use by teachers, as well as the problem of students' interest in their application (Alenezi, 2021; Fuentes and LaBad, 2025; Kalyani, 2024).

The relevance of these issues is particularly pronounced in engineering education, where contemporary curricula increasingly rely on simulation software, computer-aided design (CAD), virtual laboratories, and data-driven tools that reflect the digitalized environments in which future engineers will work (Alreiahi et al., 2024; Hsu et al., 2025). As engineering practice advances toward Industry 4.0 and 5.0 paradigms, digital competencies acquired through technology-rich learning environments have become an integral part of the professional profile expected of graduates (Broo et al., 2022). Therefore, limited

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integration of digital technologies into teaching may have long-term consequences, potentially restricting students' opportunities to develop discipline-relevant digital skills, widening the gap between educational practice and industry expectations, and reducing the perceived relevance of instruction for a generation of students accustomed to digitally mediated environments (Sjöberg et al., 2024).

Therefore, existing research indicates that in order to assess the effectiveness of the application of digital technologies in the teaching process, in addition to their availability and/or regular use, it is necessary to examine the context of students' readiness to use them. It is shown that adequate technical infrastructure of institutions, availability of digital tools for learning, as well as institutional support are most often key factors for effective implementation of digital technologies in the teaching process (Redecker, 2017; Alenezi, 2021). At the same time, due to the discrepancies between the attitude of a certain institution on the use of digital technologies and their actual application in teaching (Røe et al., 2022), it is necessary to conduct research that examines the experiences of students in relation to digital technologies within the framework of different higher education institutions and different study programs. In this sense, student engagement, which combines behavioral, emotional and social engagement, as well as cognitive investment (Bond et al., 2020; Bowden et al., 2021), in learning experiences becomes a subject of interest for future research. At the same time, students' digital literacy and their previous use of digital technologies can influence how they assess the quality of teaching, the effectiveness of communication, and the perceived value of using digital technologies (Sillat et al., 2021).

These elements are especially significant within higher education institutions emphasizing Science, Technology, Engineering, and Mathematics (STEM) fields, given that problem-solving in these domains necessitates the utilization of intricate and interdisciplinary approaches. The Faculty of Technical Sciences of the University of Novi Sad offers a wide range of study programs in the STEM field, at all levels of academic studies; basic, master and doctoral. Teaching at the faculty includes the constant development of students' skills, which gradually develop from fundamental to highly specialized research and innovation. The focus is on practical work, project-based learning and cooperation with industry, which are among the basic characteristics of STEM teaching methods.

In this study, the pedagogical value of digital technologies is understood as students' evaluation of the extent to which these technologies genuinely improve the quality of teaching and learning, rather than their mere availability or frequency of use. This understanding builds on critical accounts of technology-enhanced learning, which caution that enhancement cannot be assumed from access alone but must be judged against qualitative changes in teaching and learning processes (Kirkwood and Price, 2014). It is also consistent with evidence that students appraise digital technologies primarily in terms of their perceived usefulness for learning – supporting understanding, organisation of study, and engagement – rather than their technical novelty (Henderson et al., 2017). Perceived pedagogical value is therefore conceptually related to, but broader than, the notion of perceived usefulness in technology acceptance models, as it refers to the contribution of technologies to teaching quality and student engagement within a specific institutional context.

The aim of this study, conducted at the Faculty of Technical Sciences of the University of Novi Sad, is to examine the perception of first-year students about digital technologies. Investigating first-year students' attitudes toward digital technologies in educational contexts is particularly important, given that their initial academic encounters predominantly consist of core courses in various STEM fields. Courses such as mathematics, physics, and introductory engineering are critical in shaping students' overall learning experiences and their initial attitudes toward technology-enabled instruction. Also, because first-year students are not yet narrowly specialized, their attitudes are less affected by discipline-specific practices and more indicative of general pedagogical approaches. Consequently, exploring their perspectives offers valuable insights into the underlying acceptance, expectations, and perceived effectiveness of digital technologies in teaching, which can subsequently inform broader curricular and instructional strategies in STEM fields.

The key objective of the research was to analyze students' perceptions regarding the utilization of digital technologies in education, their integration into pedagogical practices, and their influence on the perceived quality of instruction and student involvement. The analysis focused on whether the utilization of digital resources influences students' evaluations of teachers' digital competencies and the overall quality of the educational process. The utilization of digital technologies under situations of objectively constrained resources was also examined, encompassing technological limits, software accessibility, and availability of specialist digital tools.

Theoretical Framework

The integration of digital technologies within higher education has been extensively investigated via diverse theoretical frameworks, each seeking to elucidate the determinants of technology adoption, its utilization patterns, and its impact on pedagogical practices. Prominent among these models are the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), and competence-based structures such as DigCompEdu.

Davis in 1989 introduced the Technology Acceptance Model (TAM) putting in focus as a key factors to someone's attitude towards use of technology following two things: how useful they think it is, and how easy it is to use. These beliefs then affect their intentions and, eventually, their actual use of the technology.

In higher education, TAM is often used to study how students accept digital learning systems. According to this model, tools that appear useful and simple to use tend to be evaluated more positively. However, TAM has been criticized because it focuses mainly on personal perceptions and does not fully take into account wider teaching practices, social dynamics, or institutional support, all of which also influence how technology is experienced in learning.

To address these limitations, the Unified Theory of Acceptance and Use of Technology (UTAUT), developed by [Venkatesh et al. in 2003](#), expands the Technology Acceptance Model (TAM) by adding factors like social influence and facilitating conditions. In educational settings, facilitating conditions include things like the school's infrastructure, access to digital tools, and how ready the organization is. Teachers' pedagogical approaches and their subject matter knowledge constitute significant social and instructional determinants. The findings of this study provide some support for the Unified Theory of Acceptance and Use of Technology (UTAUT), specifically by illustrating the importance of institutional support and students' digital literacy in shaping their evaluation of the educational benefits associated with digital technologies. Simultaneously, the observation that mere exposure to digital tools does not correlate with perceived value implies that frequent usage, in isolation, is insufficient; instead, more robust, pedagogically oriented justifications are warranted.

In this regard, the DigCompEdu framework ([Redecker, 2017](#)) offers a more comprehensive perspective by emphasising educators' digital competence as a key factor in designing meaningful technology-enhanced learning experiences. DigCompEdu conceptualises teachers' digital competence as an integration of technical, pedagogical, and organisational skills that enable the effective use of digital technologies for teaching and learning. Although the present study confirms that teachers' digital competence is positively associated with student engagement, its direct effect on perceived pedagogical value was not statistically significant when engagement was included in the model. This suggests that teachers' observable use of digital tools has an indirect effect, mainly by their ability to create engaging learning environments.

This study's main contribution is its emphasis on the mediating role of student engagement. Although the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) don't explicitly include engagement, current educational research increasingly views it as a key link between technology use and learning outcomes. Evidence suggests that students judge the value of digital tools mainly based on how well those tools support active participation, motivation, and cognitive involvement, rather than on the tools themselves or the teacher's technical skill ([Bond and Bedenlier, 2019](#)).

Overall, the findings show that although TAM and UTAUT are helpful for understanding factors that shape technology acceptance, they do not fully capture the educational benefits of digital technologies in higher education. Conversely, the findings align most closely with a more expansive, engagement-centric viewpoint. This perspective integrates the UTAUT model's focus on institutional backing with DigCompEdu's emphasis on teacher proficiency, while prioritizing student engagement. This more holistic framework offers a more nuanced comprehension of digital technologies' role in fostering meaningful learning; their efficacy is contingent not solely on their accessibility, but also on the effectiveness of their integration within pedagogical practices.

Materials and methods

Sample and measure

The sample included 375 first-year students from the 10 study programs at the Faculty of Technical Science, University of Novi Sad. A non-probability convenience sampling approach was adopted, with

students drawn from across the ten study programs in order to capture disciplinary diversity within the first-year cohort. First-year students were selected because, having recently transitioned from secondary to higher education, they were able to compare traditional, lecture-based teaching with technology-supported teaching. The study was approved by the Ethical Commission of the Faculty of Technical Sciences. Participants completed a paper-based survey administered in person during regularly scheduled practical (tutorial/laboratory) classes from October 21 to December 4, 2024, during the first semester of the 2024/25 academic year. The students were verbally informed about the voluntary research study and confirmed their written consent in the questionnaire.

Data were collected using a structured questionnaire comprising three conceptually distinct segments. The first segment included the respondents' basic sociodemographic characteristics (gender, study program) and self-assessment of IT skills (low, medium, high). This part also included questions related to experience and exposure to digital technologies in the teaching process, such as: the types of digital tools teachers use (multiple-choice question), dominant form of teaching (traditional, digital, combined), use of quizzes to assess knowledge, and attitude towards the use of knowledge testing applications. These variables are of categorical type and were used in descriptive and comparative analyses (Table 1).

Table 1. Characteristics of the sample (N = 375)

Variable	Categories		n	%
Gender	Female		110	29.3
	Male		265	70.7
Perceived IT skills	High		65	17.3
	Medium		252	67.2
	Low		58	15.5
Study program	Geodetic and Geomatic Engineering		33	8.8
	Energy and Process Engineering		34	9.1
	Biomedical Engineering		12	3.2
	Mechanical Design Engineering		44	11.7
	Mechanical Engineering		72	19.2
	Mechatronic Engineering		69	18.4
	Traffic Engineering		48	12.8
	Environmental Engineering		21	5.6
	Safety Engineering		23	6.1
	Disaster Risk Management		19	5.1
DT in the teaching process	Presentation	yes	363	96.8
		no	12	3.2
	Videos	yes	87	23.2
		no	288	76.8
	Animation	yes	62	16.5
		no	313	83.5
	Internet platforms	yes	71	18.9
		no	304	81.1
	AI	yes	14	3.7
		no	361	96.3
Lectures are conducted	Other	yes	2	5
		no	373	99.5
	Blackboard and chalk		109	29.1
	DT		15	4.0
Quizz	Combination		251	66.9
	yes		44	11.7
Would you like to have quizzes	no		331	88.3
	Yes		130	34.7
	No		123	32.8
	Not sure		122	32.5

The second segment consisted of a 10-question assessment on a five-point Likert scale (1 - strongly disagree to 5 - strongly agree). This part examined students' views on: the pedagogical value of digital technologies, the motivational effect of their application, the impact on the interaction between teachers and students, the effectiveness in explaining the material, and communication through digital platforms. The third segment included 8 Likert items that assessed the technical and organisational conditions for the application of digital technologies in the teaching process, including: adequacy of technical equipment, stability of the internet network, clarity and preparedness of instructions, availability of teaching materials, and the possibility of online consultation.

The instrument was developed by adapting items from four previously published survey studies and tailoring them to the STEM context. Items measuring the perceived pedagogical value and the motivational and communicational aspects of digital technologies were adapted from [Abdurashidova et al. \(2023\)](#) and from the perceived-usefulness and experience scales of [Almaiah et al. \(2022\)](#); items measuring teachers' digital competence were adapted from the tutor-quality scale of [Almaiah et al. \(2022\)](#); items on the types of digital technologies used in teaching and on institutional and infrastructural support were adapted from the [ASTI Research and Surveys \(2024\)](#) teacher survey and from [Tešanović et al. \(2019\)](#), which also informed the two-part categorical and attitudinal architecture of the questionnaire and the self-assessment of IT skills. A small number of subject-specific items were generated by the authors on the basis of preliminary interviews with students. Table 2 summarises the constructs, their indicators, and their sources.

Table 2. *Constructs, indicators, and sources of the questionnaire items*

Construct / questionnaire segment	Example indicators (items)	Source(s)
Sociodemographic characteristics and self-assessed IT skills	Gender; study program; self-assessed IT skills (low, medium, high)	Tešanović et al. (2019)
Types of and exposure to digital technologies (DT) in teaching	Presentations, videos, animations, internet platforms, AI; dominant form of teaching; use of quizzes	ASTI Research & Surveys (2024); Tešanović et al. (2019)
Perceived pedagogical value	"I prefer to attend classes that use digital technologies rather than traditional lectures."; "Digital technologies make the process of teaching and monitoring more interesting."	Abdurashidova et al. (2023); Almaiah et al. (2022)
Communication/relational value and student engagement	"Using digital technologies in teaching motivates me to be more actively involved in the learning process."; "The use of digital technologies encourages better interaction between professors and students."	Abdurashidova et al. (2023); Almaiah et al. (2022)
Teachers' digital competence	"Professors use internet platforms to communicate with students."; "Professors use digital tools effectively to explain material and communicate."	Almaiah et al. (2022), tutor-quality scale
Institutional support (Support Index)	Adequacy of technical equipment; organisation of technical support; stability of the internet network; availability of teaching materials; possibility of online consultation	ASTI Research & Surveys (2024); Tešanović et al. (2019)
Subject-specific items	Items developed on the basis of preliminary interviews with students	Authors

The psychometric quality of the instrument was established in three ways. Content validity was supported by grounding each construct in previously validated instruments (Table 2) and by review of the adapted items within the research team. Construct validity was examined through exploratory factor analysis using principal axis factoring with Varimax rotation, with sampling adequacy confirmed by the Kaiser–Meyer–Olkin measure ($KMO = .82$ and $.76$ for the two parts of the instrument) and Bartlett's test of sphericity ($p < .001$ in both cases). Items were retained on the basis of factor loadings ≥ 0.30 and theoretical coherence, as detailed in the Results section. Internal consistency was acceptable for the Perceived Pedagogical Value ($\alpha = .74$), Support Index ($\alpha = .74$) and Communication/Relational Value ($\alpha = .70$) scales. Teachers' digital competence was measured with two items adapted from the tutor-quality scale of [Almaiah et al. \(2022\)](#), in which tutor quality refers to teachers' supportive and facilitating role in technology-mediated teaching, including the use of online platforms for communication with students. The original instrument comprised 34 items across nine constructs, rated on the same five-point Likert format

used here, with internal consistency across constructs ranging from $\alpha = .76$ to $\alpha = .90$. As operationalised in the present study, the dimension is represented by only two items and therefore captures students' perceptions of teachers' use of digital tools and platforms — a narrow, behaviourally oriented indicator rather than the full construct as conceptualised in the DigCompEdu framework (Redecker, 2017), which additionally encompasses pedagogical and organisational dimensions not assessed here.

The two items measuring teachers' digital competence were adapted from a different source instrument (Almaiah et al., 2022) and refer to teachers' observable behaviour rather than to students' own experience of digital technologies in learning. Their initial communalities with the remaining items of the first segment were low (.16 and .14), indicating limited shared variance with the rest of the item pool. An exploratory solution including these items produced an improper solution, with a communality exceeding 1.0 during extraction — an outcome typical of factors defined by few indicators with little common variance (Fabrigar et al., 1999). These two items were therefore treated as an a priori two-item scale and were not included in the exploratory factor analysis.

Data analysis

In a preliminary step, all 18 Likert items were analysed jointly (KMO = .790; Bartlett's test of sphericity $\chi^2(153) = 1598.913$, $p < .001$). This joint solution yielded five factors, with items from both conceptual segments distributed across factors and no factor corresponding to either of the two intended content domains. The solution was therefore not interpretable in terms of the instrument's design. Because the instrument had been constructed a priori as two conceptually distinct segments — (1) students' perceptions of the use of digital technologies in teaching, and (2) the technical and institutional conditions supporting that use — which were intended to function as separate scales, the main analyses were conducted separately for each segment. The joint analysis is reported for transparency; it is not treated as a test of the instrument's overall dimensionality, since the two segments were not intended to form a single measurement space. The main exploratory factor analyses were conducted using principal axis factoring (PAF) with Varimax rotation and Kaiser normalization. The PAF method was selected over PCA because the goal was to identify latent constructs underlying the observed items, rather than to reduce data dimensionality (Fabrigar et al., 1999). The maximum number of iterations for convergence was set to 250; all reported solutions converged and all communalities remained within admissible bounds. Sampling adequacy was assessed using the Kaiser–Meyer–Olkin (KMO) measure, while Bartlett's test of sphericity was used to evaluate the suitability of the correlation matrix for factor analysis. The number of factors was determined on the basis of the scree plot, with the Kaiser criterion (initial eigenvalues > 1) considered as supporting evidence and interpreted together with the theoretical structure of the instrument. Items were retained on the basis of factor loadings $\geq .30$, a threshold appropriate for samples exceeding 350 respondents (Hair et al., 2018); where an item loaded above this threshold on more than one factor, it was assigned to the factor with the higher loading, and all cross-loadings are reported. Internal consistency was assessed using Cronbach's α for scales comprising three or more items. For the two-item measure, the Spearman-Brown coefficient and the inter-item correlation are reported instead, as α is systematically attenuated by scale length and is not the appropriate reliability index for two-item scales (Eisinga, Grotenhuis and Pelzer, 2013).

In the second instrument segment, internal consistency was additionally used as a secondary criterion for item selection; this is an exploratory, data-driven procedure and is acknowledged among the study's limitations.

Group differences were examined using independent-samples t-tests and one-way analysis of variance, with Levene's test used to assess homogeneity of variances. Associations between categorical variables were analysed using Pearson's chi-square test, with Cramér's V reported as the effect size. Pearson correlation analysis was used to assess relationships between continuous variables, and multiple linear regression was used to examine predictors of perceived pedagogical value; standardised beta coefficients, R^2 and adjusted R^2 are reported. Statistical significance was set at $p < .05$. All analyses were conducted in IBM SPSS Statistics v26 [34].

Results

Factor Structure of the Questionnaire

The first segment of the instrument originally comprised 10 items. Three items were not included in the exploratory factor analysis. The item "I don't have to go to class to understand the course material"

was excluded because its factor loading fell below the .30 threshold. The two items measuring teachers' digital competence were treated as an a priori two-item scale, for the reasons set out in Section "Sample and measure", and were analysed separately (see below). Exploratory factor analysis was therefore conducted on the remaining seven items.

Table 3. *Rotated factor matrix of the first part of the Instrument*

Items	Factors' loadings	
	1	2
I prefer to attend classes that use digital technologies rather than traditional lectures.	.731	.239
Digital technologies make the process of teaching and monitoring more interesting.	.770	.205
Multimedia content helps me understand the material better.	.374	.335
The use of digital technologies enables more efficient acquisition of new knowledge.	.449	.347
Using digital technologies in teaching motivates me to be more actively involved in the learning process.	.429	.611
The use of digital technologies encourages better interaction between professors and students.	.264	.628
I have the impression that professors devote more time to lectures when they use digital technologies in their teaching.	.122	.561

Note: Extraction method: principal axis factoring. Rotation method: Varimax with Kaiser normalisation. Loadings in bold indicate the factor to which the item was assigned.

The Kaiser-Meyer-Olkin measure of sampling adequacy was good ($KMO = .816$), and Bartlett's test of sphericity was statistically significant ($\chi^2(21) = 729.08$, $p < .001$), indicating that the data were suitable for factor analysis. Principal axis factoring converged in 13 iterations, and Varimax rotation converged in 3 iterations; all extracted communalities were within admissible bounds. A two-factor solution was retained on the basis of the Kaiser criterion (initial eigenvalues of 3.21 and 1.00), the theoretical structure of the instrument, which distinguishes pedagogical from communication/relational value, and the interpretability of the resulting factors. The scree plot (Figure 1) indicates a pronounced break after the first factor; the second factor is therefore modest in magnitude, and this is noted among the study's limitations. The two factors accounted for 24.80% and 20.20% of the variance respectively (rotation sums of squared loadings), or 45.00% cumulatively — a moderate but reasonable value for instruments of this type (Hair, Black, Babin and Anderson, 2018). The item structure and factor loadings are presented in Table 3.

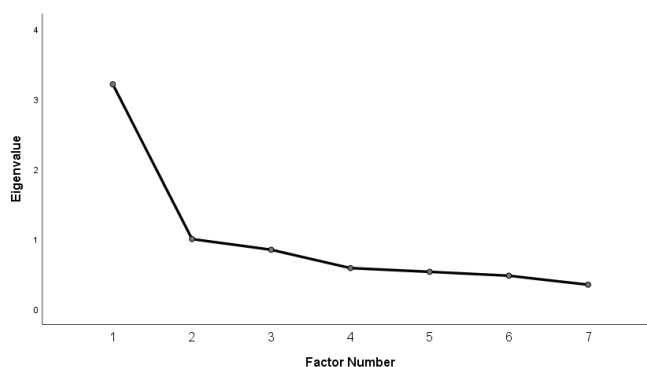


Figure 1. *Scree plot for the first part of the Instrument*

The first factor, labelled Perceived Pedagogical Value, comprises four items concerning the contribution of digital technologies to the quality and attractiveness of teaching. The second factor, labelled Communication/Relational Value, comprises three items concerning the effects of digital technologies on motivation and on communication between teachers and students. Three items loaded above .30 on both factors and were assigned to the factor with the higher loading; all loadings are reported in full in Table 3. For one item ("Multimedia content helps me understand the material better") the two loadings were of comparable magnitude (.374 and .335), and its assignment should therefore be regarded as provisional. Communalities for three items were below .35; with communalities in this range, larger samples are required for stable factor recovery, a condition met by the present sample of 375 respondents (MacCallum, Widaman, Zhang and Hong, 1999). Teachers' digital competence was represented by the two items

adapted from [Almaiah et al. \(2022\)](#) and was not derived from the exploratory factor analysis. Reliability for this two-item measure is expressed as the inter-item correlation ($r = .353$) and the Spearman-Brown coefficient ($SB = .52$); Cronbach's α is not an appropriate index for two-item scales ([Eisinga, Grotenhuis and Pelzer, 2013](#)). The limitations of this measure are addressed in the Limitations section.

The second part of the instrument includes 8 items related to institutional support and the utilisation of digital technology. The PAF analysis was conducted ($KMO = .763$), and Bartlett's test of sphericity was statistically significant ($\chi^2 (21) = 532.79$, $p < .001$). Although the Kaiser criterion yields 2 factors (>1), the other is borderline, and the scree plot clearly supports a single factor (Figure 2), named Support Index, consisting of 7 items and explaining 40.1% of the variance; item "Professors give advantages to digital technologies" was removed because its exclusion improved the internal consistency of the scale. The Support Index item structure and factor loadings are represented in Table 4.

Table 4. Factor matrix of the second part of the Instrument

Items	Factors' loadings
The faculty where I study has adequate technical equipment that is needed for the unhindered use of digital technologies in the teaching process.	.634
Technical support for digital technologies at the faculty is well organised.	.719
Classrooms are connected to a fast, stable internet network.	.512
The instructions I receive for the use of digital technologies in teaching are adequately prepared.	.615
I have adequate equipment for accessing digital materials from home.	.404
The material used in the lectures is easily available.	.546
Consultations with professors and assistants are available via online platforms.	.465

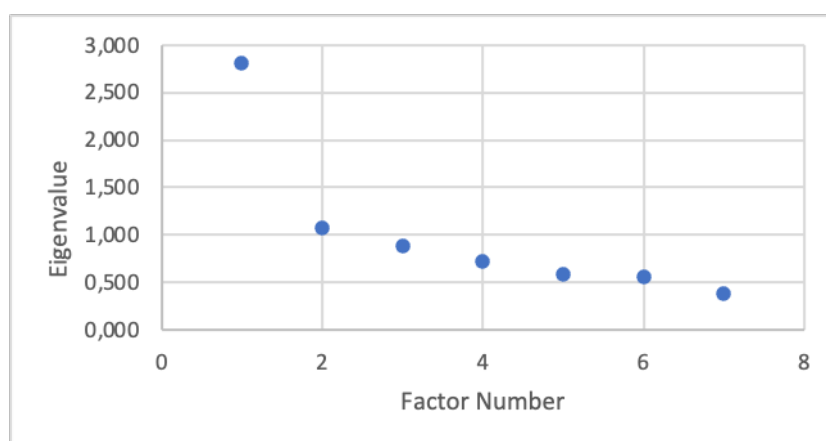


Figure 2. Scree plot for the second part of the Instrument

The skewness and kurtosis for all scales do not exceed ± 2 , indicating that the normality assumption is not violated ([West et al., 1995](#)). Internal consistency was acceptable for the three multi-item scales; for the two-item Teachers' Digital Competence measure, the inter-item correlation (r) and the Spearman-Brown coefficient (SB) are reported instead, as Cronbach's alpha is not an appropriate reliability index for two-item scales. Reliability estimates and descriptive statistics for all scales are presented in Table 5. There is a positive correlation between perceived pedagogical value and communication/relational value ($r = .55$, $p < .001$), between perceived pedagogical value and teachers' digital competence ($r = .128$, $p = .013$), and between perceived pedagogical value and support index ($r = .192$, $p < .001$). The remaining correlations between factors were also statistically significant.

Table 5. Descriptive statistics and internal consistency of instrument scales

Instrument scales	M	SD	Sk	Ku	α / r; SB
Perceived pedagogical value	3.64	0.75	-0.40	0.23	0.74
Communication/relational value	3.02	0.92	-0.03	-0.36	0.70
Teachers' digital competence	3.76	0.89	-0.39	-0.31	0.35; 0.52
Support Index	3.67	0.73	-0.24	-0.36	0.74

Note: M = mean; SD = standard deviation; Sk = skewness; Ku = kurtosis; α = Cronbach's alpha; inter-item correlation (r) and the Spearman-Brown coefficient (SB)

Descriptive statistics indicate a moderately positive perception of the pedagogical value of digital technologies (M = 3.64; SD = 0.75) and the digital competence of teachers (M = 3.76; SD = 0.89), while communication/relational value is closer to the neutral value (M = 3.02, SD = 0.92).

DT exposure

Descriptive analysis shows that the average value of the index of exposure to digital technologies in teaching was M = 0.62 (SD = 0.81), with values ranging from 0 to 4. These results indicate that, on average, students are exposed to fewer than one additional advanced digital tool in the teaching process. Although there is some variability in responses, the overall level of exposure remains relatively low. The exposure to DT, depending on the type of study program, is shown in Figure 3.

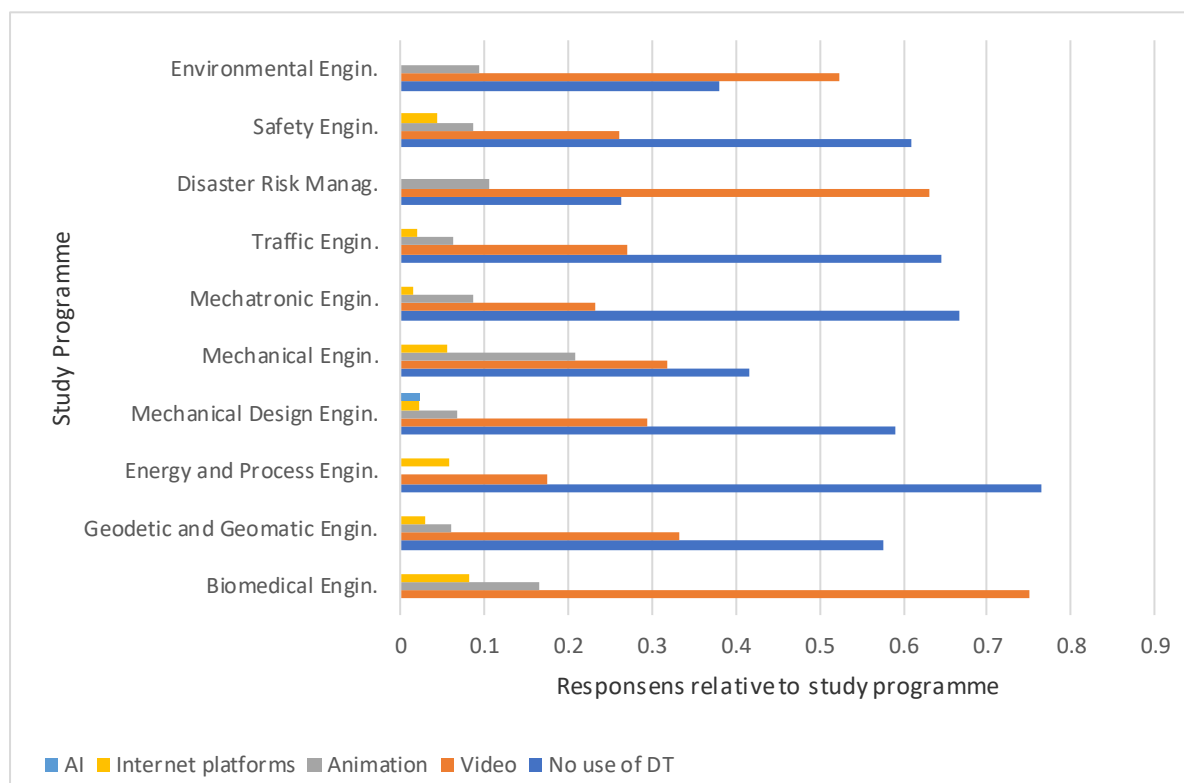


Figure 3. Students' attitude towards DT exposure regarding study programme

Group difference

To examine whether there are gender differences in perceptions of digital technologies in the teaching process, an analysis of group differences was conducted. The analysis did not show statistically significant differences between male and female subjects for the variables examined ($t(373) = -0.51$, $p = 0.613$).

To investigate whether there are differences in perceptions of the pedagogical value of digital technologies across students' self-assessed IT skill levels, a one-factor analysis of variance (ANOVA) was conducted. The assumption of homogeneity of variances was satisfied (Levene's test, $p = .431$). The results of the ANOVA showed a statistically significant difference among the groups, $F(2, 372) = 5.41$, $p = .005$.

Post hoc Tukey test showed that students with high IT skills had significantly higher scores on the perceived pedagogical value of digital technologies scale ($M = 3.90$) compared to students with medium ($M = 3.62$, $p = .019$) and low ($M = 3.47$, $p = .005$) IT skills. The difference between students with medium and low IT skills was not statistically significant ($p = .397$).

A crosstab analysis was conducted to examine whether students' exposure to advanced digital technologies in the classroom differed between study programs. The results showed a statistically significant association between the study program and the DT exposure index ($\chi^2(36) = 65.88$, $p = .002$, Cramer's $V = 0.21$), indicating a small-to-moderate effect size. In total, more than half of students (54.7%) reported no exposure to advanced digital tools in class, while 32.0% reported exposure to one tool, and only a minority reported exposure to two or more tools. The distribution of the DT exposure index differed across study programs, indicating that students in different fields have varying levels of integration of digital technologies in the teaching process.

Regression analysis

To identify the significant predictors of perceived pedagogical value, a series of regression analyses was done. The initial focus was on examining the relationship between teachers' digital competence, student engagement, digital exposure, IT students' competence, and institutional support with the initial variable. The findings reveal the following results.

Teachers' digital competence is a statistically significant but weak predictor of student engagement ($\beta = 0.110$, $p = .033$), accounting for only 1.2% of the variance in this construct ($R^2 = 0.012$). Student engagement then proved to be a strong predictor of the perceived pedagogical value of digital technologies ($\beta = 0.551$, $p < .001$), explaining 30.4% of the variance of the dependent variable ($R^2 = 0.304$). When teachers' digital competence and student engagement were simultaneously included in the model for predicting the perceived pedagogical value of digital technologies, student engagement remained a statistically significant predictor ($\beta = 0.544$, $p < .001$), while the direct effect of teacher digital competence was no longer statistically significant ($\beta = 0.069$, ns). These results indicate that student engagement mediates the relationship between teachers' perceived digital competence and the perceived pedagogical value of digital technologies. In order to get a more complete understanding of the factors influencing the perceived pedagogical value of digital technologies, the model was extended to include additional variables related to institutional support, students' IT skills, and classroom exposure to digital technologies. A multiple regression analysis was conducted that included, in addition to the above variables, the index of institutional support, students' IT competence (a dichotomous variable indicating higher or lower levels of students' self-assessed IT skills), and the index of exposure to digital technologies (DT exposure). The overall model was statistically significant ($F(5, 369) = 37.560$, $p < .001$) and explained 33.7% of the variance in the perceived pedagogical value of digital technologies ($R^2 = 0.337$).

In this expanded model, student engagement again emerged as the strongest predictor ($\beta = 0.524$, $p < 0.001$). In addition, the index of institutional support ($\beta = 0.126$, $p = .010$) and students' IT competencies ($\beta = 0.135$, $p = .002$) made statistically significant contributions to the model. In contrast, teachers' digital competence ($\beta = 0.011$, $p = .815$) and exposure to digital technologies in teaching ($\beta = 0.024$, $p = .582$) were not significant predictors when other variables were included.

These findings indicate that the perceived pedagogical value of digital technologies in teaching largely depends on student engagement, the level of institutional support, and students' digital competencies.

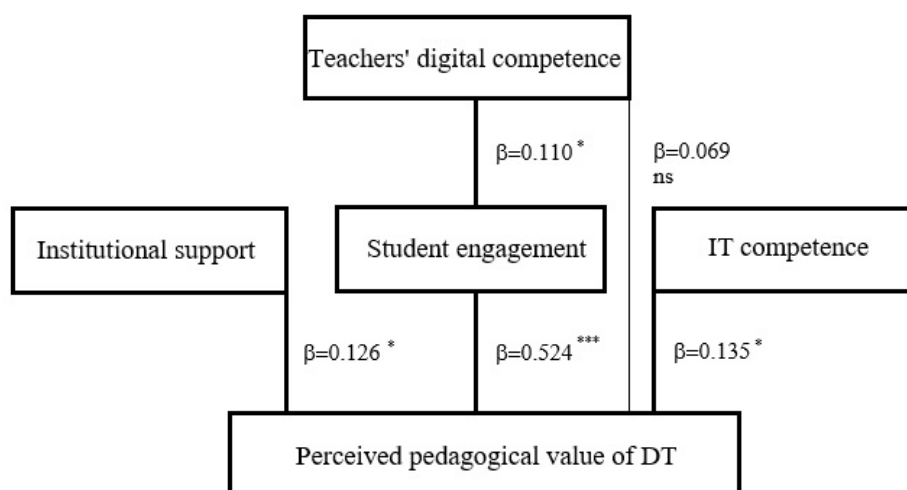


Figure 4. Regression model of the relationships among teachers' digital competence, student engagement, and the perceived pedagogical value of DT ($p < .05$, *** $p < .001$, ns=not significant)

Overall, the results indicate that although students express a positive perception of digital technologies and of teachers' digital competence, the integration of advanced digital tools into the teaching process remains relatively limited. In addition, student engagement has been shown to be a key factor associated with the perceived pedagogical value of digital technologies.

Discussions

This study examined first-year engineering students' perceptions of digital technologies (DT), their representation in teaching, and the factors that predict the perceived pedagogical value of DT at the Faculty of Technical Sciences (FTN), University of Novi Sad. In relation to these objectives, three main findings emerged. First, although students held moderately positive views of DT and of teachers' digital competence, their exposure to advanced digital tools was limited and fragmented. Second, regression analyses identified student engagement as by far the strongest predictor of perceived pedagogical value ($\beta = 0.524$, $p < .001$), followed by smaller but significant contributions of students' IT competencies ($\beta = 0.135$, $p = .002$) and institutional support ($\beta = 0.126$, $p = .010$), with the full model explaining 33.7% of the variance. Third, teachers' digital competence and exposure to DT were not significant predictors once engagement was taken into account. Taken together, these findings indicate that students judge the value of DT primarily by its capacity to foster active participation, which is consistent with engagement-centred accounts of technology-enhanced learning (Bond et al., 2020; Henderson et al., 2017) rather than with acceptance models that foreground technology attributes alone. This is in agreement with previous findings showing that the effectiveness of digital tools in higher education depends more on how they are pedagogically embedded than on their technical sophistication (Henderson et al., 2017; Kirkwood and Price, 2014).

The participant group included 375 first-year students from ten different academic programs. The distribution of responses across these programs was as follows: Biomedical Engineering (12 participants), Geodesy and Geoinformatics (33 participants), Energy and Process Engineering (34 participants), Mechanical Design Engineering (44 participants), Mechanical Engineering (72 participants), Mechatronics Engineering (69 participants), Traffic Engineering (48 participants), Disaster Risk Management (19 participants), Safety Engineering (23 participants), and Life Safety Engineering Environment (21 participants). Among the responders, 70.7% are male and 29.3% are female.

Results show students' low exposure to advanced digital technologies. This finding must be interpreted in relation to the actual types of DT used at the Faculty of Technical Sciences. Although digital tools are employed in presentations with near universal prevalence (96.8%), the integration of more interactive or conceptually advanced formats, such as videos (23.2%), animations (16.5%), and internet platforms (18.9%), is significantly less common. The use of AI tools is minimal, at 3.7%. Conversely, while the integration of these resources improves the core organization and structure of course content, it does not provide the heightened interactivity, feedback, and collaborative opportunities that often foster greater

student engagement with the learning process. As a result, exposure to digital technologies did not significantly correlate with perceived pedagogical value. Students generally viewed digital technologies as beneficial for learning. The evaluations showed mostly positive results, with an average score of 3.64. In contrast, students' understanding is mainly based on basic technologies and teaching methods, rather than on complex, interactive resources. This observation is consistent with studies indicating that digital technologies (DT) characterized by low complexity and a focus on presentation fail to fully exploit technology's pedagogical capabilities (Baddar and Khan, 2023; Zou et al., 2025; Bond et al., 2020).

Furthermore, in many programs, a significant number of students reported not having much experience with advanced digital technologies. This was especially pronounced in Energy and Process Engineering, Mechatronic Engineering, Traffic Engineering, Geodetic and Geomatic Engineering, and Safety Engineering, where over half of the participants indicated that such tools were not utilized in their instruction. This suggests that traditional or basic forms of digital support continue to dominate instructional approaches in these fields, which is consistent with previous research showing that higher education teaching often relies on low-complexity digital tools rather than more advanced or interactive technologies (Henderson et al., 2017; Kirkwood and Price, 2014).

Where exposure is present, it is most commonly limited to a single digital tool, as observed in programmes such as Biomedical Engineering, Disaster Risk Management, and Environmental Engineering, indicating a partial but still relatively narrow integration of digital technologies. In contrast, programmes like Mechanical Engineering and Mechanical Design Engineering show a more balanced distribution, although even in these cases, the use of multiple advanced tools remains limited. Across all programmes, exposure to two or more advanced digital technologies is consistently low, and the use of a broader range of tools is almost absent. These patterns suggest that digital technologies are not systematically embedded into teaching processes but are instead applied in a fragmented and surface-level manner. Furthermore, the observed differences between study programs suggest that the use of digital tools varies by discipline. This likely reflects differences in how curricula are structured, how teaching is done, and the resources available at each institution (Bond et al., 2020). The data suggests that students' chances to engage with diverse and interactive digital learning environments are limited. This could hinder the potential of digital technologies to create more meaningful and transformative learning experiences.

Although only 11.7% of the people surveyed said they used quizzes to assess knowledge during lectures, 34.7% of the students wanted to use more tools for evaluating knowledge in class. The limited use of quizzes in education is mainly due to the need for licenses for many users on most platforms, such as Kahoot, Mentimeter, and Quizizz, which the faculty currently doesn't have. Interestingly, 32.5% of students are unsure about quizzes, while 32.8% prefer not to use them to assess their understanding. This outcome is likely attributable to the ambiguous phrasing of the question, which fails to underscore the anonymity of student participants. These quizzes can enhance the educational process by providing not only a knowledge assessment at the conclusion of lectures but also by awarding participants with the top scores a specific amount of credit towards pre-examination requirements.

Findings related to individual characteristics suggest that gender does not appear to be a strong differentiating factor in students' perceptions of digital technologies or institutional support within this context. This aligns with meta-analytic evidence indicating that gender differences in DT use and skills are generally small and statistically insignificant in many modern student populations, particularly where digital experience is widespread (Qazi et al., 2022). However, it is important to acknowledge that some studies continue to report context specific gender variations in digital skills and attitudes, demonstrating that such differences, while reduced, have not been entirely eliminated (Campos and Scherer, 2024).

The notable disparities observed among IT skill groups align with existing research (Le et al., 2022). Students' self-evaluated digital literacy influences their ability to navigate digital resources and their overall disposition toward technology-integrated learning. While a higher self-reported digital literacy doesn't always correlate with academic success, it consistently influences how students engage and how they perceive digital learning environments. Students with higher digital literacy rated the pedagogical value more positively. This finding supports the idea that a student's readiness influences how they use digital tools and how they assess their usefulness.

At the study program level, the findings suggest a variance in students' engagement with sophisticated digital technologies, contingent upon their specific study programs. This observation implies that the integration of digital resources is not uniform across academic fields, echoing previous research that highlights dis-

disciplinary differences in the adoption and pedagogical utilization of digital technologies (Bond et al., 2020).

The considerable proportion of students indicating minimal interaction with advanced digital tools may be explained by instructional approaches that emphasize fundamental technologies, including presentation software and learning management systems, with more interactive and complex applications being utilized less often (Henderson et al., 2017; Kirkwood and Price, 2014). These observations support the view that digital transformation in higher education is a fragmented and context-dependent process, shaped by differences in pedagogical design, instructor proficiency, and institutional resources (Tondeur et al., 2017; Bond et al., 2018).

Relatively neutral perception of the communication/relational value of DT that students have is consistent with the infrequent use of tools that support two way communication, such as learning platforms, online communication channels, and formative quizzes. With limited opportunities for structured teacher to student or peer to peer interaction students perceive fewer interpersonal or motivational benefits from DT, which caps perceived value. Similar research demonstrates that in order to improve the relational and motivating aspects of learning, communication-oriented technology must be regularly and meaningfully integrated (Baddar and Khan, 2023). Classroom formats at FTN reinforce this pattern. Most students experience a hybrid but predominantly traditional teaching model a combination of blackboard and digital tools (66.9%), while 29.1% attend fully traditional classes and only 4% experience DT only instruction. In such environments, DT is often used as an add on to a lecture centered approach rather than as a vehicle for active learning. Consequently, student engagement (the strongest predictor of perceived value) depends more on teachers' pedagogical orchestration than on the presence of DT itself. When digital technology (DT) isn't integrated into practical, or collaborative learning, its perceived teaching benefits are limited. This aligns with previous research, which shows that teachers need both structural and teaching support to move beyond basic technology use (Le et al., 2022). Students generally viewed digital technologies as pedagogically valuable and rated teachers' digital skills positively. This is consistent with earlier studies that found a link between teachers' skills and their intention to use digital resources (Baddar and Khan, 2023; Wadmany and Kliachko, 2014). However, in this study, the measured aspect of teachers' digital competence had only a small direct effect on perceived pedagogical value. Once student engagement was added to the model, its effect disappeared. This implies that students only find teacher competence valuable when it leads to engaging and interactive learning. In settings where presentations and a mix of traditional and modern teaching methods are common, competence is evident, but its impact may be limited (Wadmany and Kliachko, 2014). This finding contrasts with studies that treat teachers' digital competence as an independent driver of perceived instructional quality (Baddar and Khan, 2023; Wadmany and Kliachko, 2014); the present results suggest that its influence is conditional and largely mediated by student engagement, extending prior work by clarifying the mechanism through which competence translates into perceived value.

Student engagement was the most important factor in determining perceived pedagogical value, accounting for over 30% of the observed differences. Notably, the standardized coefficient for student engagement ($\beta = .524$) was considerably larger than those for institutional support ($\beta = .126$) and students' IT competence ($\beta = .135$), indicating that its contribution to perceived pedagogical value was approximately four times stronger than that of the other two significant predictors. This disproportionate weight can be explained through the lens of active learning and interaction-based theories of learning (e.g., Bond et al., 2020), which posit that behavioral and cognitive investment in the learning process is a more proximal determinant of perceived instructional value than the availability of resources or infrastructure per se; institutional support and digital competence appear to function as enabling conditions, whereas engagement operates as the mechanism through which these conditions translate into perceived value. This is consistent with research in STEM education showing that engagement is strengthened when digital tools are interactive, accessible, and support communication and independent learning (Le et al., 2022; Zakrzewski and Newton, 2022). The pattern of results further suggests that student engagement may operate as a mediating mechanism between technological resources and students' evaluations of teaching; however, as a formal mediation analysis (e.g., structural equation modelling) was beyond the scope of this study, this interpretation should be treated as tentative and represents a valuable direction for future research.

Furthermore, institutional support exhibited a significant positive correlation with perceived pedagogical value. This aligns with previous research highlighting the importance of infrastructure, reliable internet access, easily available materials, and clear guidance (Huong et al., 2025). When these conditions are met, even basic digital tools can be used effectively, reducing obstacles for students and encouraging

positive attitudes. Furthermore, systematic reviews of STEM education show that institutional challenges, such as insufficient curriculum support, limited opportunities for peer collaboration, and inadequate professional development, significantly hinder the use of digital technologies in education (Margot and Kettler, 2019). These broader findings are reflected in the relatively infrequent use of advanced digital tools seen in the current sample.

The consolidated research findings address the research objective by indicating that the perceived pedagogical value of digital technologies in engineering higher education is determined less by their mere availability and use, and more by the extent to which their application fosters student engagement, supported by institutional backing and students' competencies. Therefore, these findings extend technology-based engagement learning models by demonstrating that teachers' digital competence and institutional support function as enabling conditions rather than direct determinants of perceived pedagogical value. From a practical perspective, the findings suggest that institutional investments focused solely on improving teachers' digital skills or technological infrastructure are unlikely to enhance perceived pedagogical value unless they are accompanied by pedagogical strategies that actively promote student interaction and participation.

This study, while contributing to the field, has some limitations that should be considered in relation to the results. As the study employed a cross-sectional design, the regression models identify predictive contributions rather than causal effects; therefore, the term 'influence' should be understood in a predictive, not causal, sense. The study's conclusions are based on self-reported assessments of digital skills and participation. These assessments are subject to personal biases and individual differences in how people respond. Future studies could improve survey methods by including objective measures of digital learning behaviors. These could involve learning analytics, performance data, or direct observations of classroom interactions. This methodological triangulation would contribute to a more comprehensive understanding of the fundamental processes that shape technology-enhanced learning environments.

The present study was undertaken within a single institution, concentrating on first-year students enrolled in STEM programs within a single faculty in Serbia. This specific focus provides valuable perspectives on initial academic interactions with digital technology; however, it may limit the generalizability of the results to other academic fields, educational structures, or higher levels of study. Comparative studies across multiple institutions could clarify the influence of organizational culture, curriculum design, and national digitization initiatives on students' perceptions of digital pedagogical approaches.

Several further limitations concern the instrument. First, teachers' digital competence was assessed with only two items capturing observable use of digital tools and platforms; factors defined by fewer than three indicators are weakly determined (Fabrigar et al., 1999; Velicer and Fava, 1998), and the measure covers only part of the DigCompEdu construct. Its non-significant direct contribution in the regression model should therefore not be read as evidence that teachers' digital competence is unimportant, as the estimate is likely attenuated by measurement error and by the limited content coverage of the measure. Confirmatory factor analysis on an independent sample, with an expanded item pool for the teachers' digital competence dimension, is a necessary next step. The second factor identified in the first instrument segment was also modest in magnitude (initial eigenvalue = 1.00, accounting for 20.20% of the variance after rotation), and the scree plot indicates a pronounced break after the first factor. Its stability should therefore be confirmed on an independent sample. Third, in the second instrument segment one item was removed on the basis of internal-consistency criteria, an exploratory procedure that may capitalise on sample-specific variation.

Future research should explore the qualitative aspects of student engagement in digitally enhanced STEM learning environments. A thorough examination of how digital resources support complex thinking and collaborative knowledge creation could help us better understand the conditions that allow digital technologies to create impactful and transformative learning experiences.

Conclusion

This study set out to examine first-year engineering students' perceptions of digital technologies (DT) and to identify the factors that shape the perceived pedagogical value of DT in teaching at a technical faculty. In direct response to this objective, the study yields a clear main finding: student engagement is the decisive determinant of perceived pedagogical value, accounting for the largest share of explained variance ($\beta = 0.524$; model $R^2 = 0.337$), whereas teachers' digital competence and the level of exposure to

digital tools are not significant predictors once engagement is taken into account. Students' self-assessed digital competencies and institutional support make smaller but significant additional contributions. Thus, the perceived value of digital technologies at the technical faculty depends primarily on the degree to which technology-supported teaching actively involves students, rather than on the availability of tools or teachers' technical proficiency as such. At the same time, although students generally held positive views of DT and of their teachers' digital skills, their actual use of advanced digital tools remained limited, revealing a gap between the pedagogical potential of technology and its realised use in practice.

The significance of student engagement underscores the imperative for instructional strategies that foster active involvement, interactive experiences, and the purposeful utilization of digital tools. Moreover, the substantial impact of institutional support underscores the requirement for a strong technical infrastructure, readily available digital resources, and structured guidance elements proven essential for effective technology enhanced instruction.

At the same time, the limited use of digital technologies and the differences seen across various study programs align with known institutional and structural challenges. These challenges hinder educators' ability to consistently integrate advanced technologies. These findings highlight the importance of collaborative efforts within institutions that should integrate curriculum development, and strategic investments in digital infrastructure. This is crucial to ensure that technology integration is both pedagogically sound and consistently applied.

This study essentially adds to the existing knowledge by showing that the perceived value of digital technologies in education goes beyond just the teacher's skills or how easy the tools are to use. Instead, it's a complex idea influenced by factors related to students, teachers, and the institution. Subsequent investigations should build upon these findings by exploring how specific pedagogical designs affect engagement, how digital competence develops over time, and how discipline specific digital practices may explain the observed disparities among study programs. Consequently, by addressing these dimensions, institutions can more effectively utilize digital technologies to foster high quality learning experiences within STEM education.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author/s.

Institutional Review Board Statement

This study was conducted in accordance with the ethical standards of the University of Novi Sad, Faculty of Technical Sciences (01-1254).

Author Contributions

Conceptualisation, I.L., S.S.C. and R.L.; Methodology, S.S.C, I.L. and R.L.; Formal analysis, S.S.C; Writing—original draft preparation, I.L and S.S.C.; Writing—review and editing, I.L. and S.S.C.; Data curation, S.S.C and R.L.; Investigation, R.L. and I.L.; Resources R.L.; Supervision I.L., and S.S.C.; Validation I.L. and S.S.C.; Visualisation, R.L. All authors have read and agreed to the published version of the manuscript.

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Career Perspectives of Teacher Education Students: Choice, Satisfaction and Expectations

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Abstract: The aim of this study was to examine the perceptions of the teaching profession, satisfaction with the choice of a study programme, and desirable work values in students in their final years of various areas of teacher education studies. The study participants were 443 students in their final year of teacher education studies in the Republic of Croatia. The participants filled out the questionnaires designed to examine their intentions of finding a job in their professional field, their satisfaction with the chosen study programme, the perception of the support received from their surroundings, their satisfaction with a study programme, and the perception of the teaching profession and desirable work values. The findings have shown that students tend to rank highly expert career and high demand of the teaching profession, while they give the lowest ranking to the social status of teachers and their salary. Statistically significant differences were found in almost all of the examined variables with regard to the area of study (interdisciplinary, humanistic, STEM, social). The perceptions of students who intend to find employment in schools are statistically different in comparison with those of students who do not intend to or who are not sure whether they would work in schools, with regard to their satisfaction with the chosen study programme and studies, and their perceptions of the important work values. The logistic regression analysis results indicate that satisfaction with the chosen study programme is the most important factor contributing to students' intentions to find employment in school. The findings highlight the importance of strengthening professional orientation and providing support to students during their studies, while future research should further examine the factors underlying satisfaction with the choice of a study programme.

Keywords: *intention of performing work, perceptions of the teaching profession, satisfaction with the choice of a study programme and studies, teacher shortages, the importance of work.*

Introduction

A vast body of research confirms that teachers are the most important factor associated with school that has an impact on student learning and academic success (Chetty et al., 2014). In spite of that, throughout the last two decades, numerous education systems around the world have been facing shortages of qualified teachers in schools (Nguyen et al., 2020). Considering the current teacher shortages and teacher demand, it is estimated that by 2030, there will be a shortage of approximately 44 million teachers in primary and secondary schools on the global level (UNESCO and International task force on teachers for education 2030, 2024). This teacher shortage points to a need to understand thoroughly the factors that influence teacher retention and their professional motivation.

In the available literature, teacher turnover has been analysed from two complementary dimensions: teacher attrition and teacher migration. Teacher attrition includes leaving the teaching profession, while teacher migration implies a change of school or workplace within the same school. Contrary to attrition, teacher retention implies a decision to stay in the teaching profession, either performing the same job in the same school or performing the same job in a different school (Gundlach et al., 2024). Though it may seem that a change of school does not reduce the total number of in-service teachers, research reveals negative consequences of such changes affecting both teachers and their colleagues (Hahs-Vaughn and

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Scherff, 2008; Ingersoll, 2001), while teacher attrition has a much more significant impact.

Teacher attrition as a result of teachers leaving their profession results in many consequences, including the financial costs arising from their replacement and training of new teachers. These costs may range from 10,000 to 20,000 dollars per teacher (Allen et al., 2016; DeFeo et al., 2017). Apart from the teachers who have already gained work experience, more attention is paid to teacher education students who do not plan to work in schools upon completion of their studies. Elstad et al. (2021) define turnover intention as a student's intention to leave the teacher education studies or the teaching profession after they have completed the studies. Research findings from Belgium indicate that only 69 – 95% of teachers with a university degree decide to find employment in a primary school, 64 – 78% of them are willing to start working in lower grades of secondary school, and only 21 – 46% plan to find a job in higher grades of secondary school (Rots et al., 2014).

According to a report by the Organisation for Economic Co-operation and Development (OECD, 2019), teacher shortage and lower teacher education studies enrolment rates are among the greatest challenges education systems are facing on the global level. In order to solve this problem, the researchers point to a need to examine the motives which affect one's decision to enrol in teacher education studies (González Sanzana et al., 2024). Goller et al. (2019) claim that motivation for choosing the teaching profession is a predictor of the teacher education students' success, as their motivation has a significant influence on their engagement in the studies (Kissau et al., 2019), commitment to their profession (Fokkens-Bruinsma and Canrinus, 2014), and persistence in the teaching career (McLean et al., 2019). Therefore, it can be concluded that motivated teachers are a key factor influencing the quality of any education system.

In the Republic of Croatia, no comprehensive research on the shortage of qualified educators has not been published, although some studies indicate a shortage of educators and a decreased interest in enrolling into teacher education studies. Domović and Drvodelić (2025) emphasize the continuing shortage of all subject teacher profiles (Grades 5 – 8 in primary school), especially in the STEM area. Previously conducted studies were mostly focused on examining the work of novice teachers and/or teachers with longer work experience. However, there is still a lack of studies focusing on the analysis of teacher education students' perceptions. Therefore, with the aim of filling the research gap, this study will focus on examining the perceptions of teacher education students in various areas of study and analysis results. It will facilitate a deeper understanding of the choice of a study programme, satisfaction with the chosen study programme, the perceptions about the teaching profession and desirable characteristics of the future profession, which will create important implications for potential future actions.

Theoretical framework

The choice of a study programme

In order to comprehend the motives for choosing the teaching profession, the literature frequently presents the FIT (Factors Influencing Teaching)-Choice model developed by Watt and Richardson (2007). This model was used in the study as a conceptual framework and it encompasses multiple dimensions. For the purposes of this study, various scales were used to assess the choice of a study programme (Social dissuasion, Satisfaction with the choice of a study programme) and the perceptions of the teaching profession (Social status, Salary, Expert career, High demand). Fokkens-Bruinsma and Canrinus (2012) point out that there are other motives for choosing the teaching profession mentioned in the literature, such as material aspects (job stability), professional aspects (interest in a certain scientific area or school subject), and altruistic aspects (love and responsibility for improving the well-being of children and young people). The decision to choose the teaching profession can also be made under the influence of people from the immediate social environment who may offer support and encourage a person to enrol into teacher education studies (Richardson and Watt, 2006).

Satisfaction with a study programme

Providing students with quality study programmes and additional services is crucial for the survival of higher education institutions in an environment which has become increasingly competitive (Lapina et al., 2016; Paul and Pradhan, 2019). Student satisfaction is positively related to motivation, academic achievement and student retention at the faculty (Duque, 2014; Mihanović et al., 2016; Nastasić et al.,

2019). It also has a positive impact on the rating of educational institutions and student achievement. A majority of scientists perceive student satisfaction as a multidimensional construct (Duque, 2014; Wach et al., 2016; Wong and Chapman, 2023). Wong and Chapman (2023) list eight aspects of student satisfaction which they classified into three categories: academic (satisfaction with the study programme and the teaching process), institutional (satisfaction with the educational institution, the learning space and equipment at the university, and the support offered), and student life at university (satisfaction with their own learning process, the overall university experience and overall student life at university). Other important elements of student satisfaction mentioned in the literature are: university climate, student-oriented teaching, empathy, teacher competencies, curriculum, student-student interaction, student-teacher rapport, group size, lectures held according to the schedule, and the availability of the teaching materials (Douglas et al., 2006; Elliot and Healy, 2001; Wong and Chapman, 2023).

The perception of the teaching profession

Young people shape the professional identity of a future teacher even before they embark on their academic career. The initial professional identity is influenced not only by personal factors but also by a broader social context observed by a young person, such as how much the teaching profession is appreciated in the society or what attitudes people important to them (parents, peers) have regarding the teaching profession (Torres-Cladera et al., 2021). Before opting for the teaching profession, young people have gained an extensive experience of the teaching profession as students. It also includes their interest in the courses, academic achievement, peer interactions and interactions with their teachers, as well as their overall impression of school. Social dissuasion and personal experience may either encourage or discourage them to choose the teaching profession (Bergmark et al., 2018).

Motivation for teaching is crucial when choosing the teaching career, both during the course of teacher education studies and later on in the teaching career itself (Sinclair, 2008). Intrinsic and altruistic motivation are dominant when choosing the teaching profession (Tang et al., 2015). However, Sinclair (2008) points out that intrinsic motivation and enthusiasm may subside over time, as teachers are overwhelmed with work and are not provided with the necessary support in their working environment, resulting in teacher attrition (Kim and Cho, 2014).

Desirable work values

Numerous concepts are being studied with regard to the workplace context, including work values. Analysing the relevant scientific literature, Lyons et al. (2010) describe work values as general beliefs about the relative desirability of various aspects of work (e.g., working conditions, salary, autonomy) and work-related outcomes (e.g., achievement, prestige). Work values may be considered as internal expressions of various needs or outcomes which individuals are trying to meet or achieve with their work, including intellectual, social, and status needs, needs for respect and self-realization. Work values indicate what each individual finds important in their work (Kuron, 2015). They organize work values in hierarchical order, according to their importance, and use the set hierarchy as a reference point when making decisions related to work and career (Lyons, 2010). There are also numerous classifications and approaches to measuring workplace values, but in general, they can be classified into the following categories: intrinsic, extrinsic, altruistic, and prestigious workplace values (Lyons and Kuron, 2014) and this study measures work values across these established dimensions.

The aim and problems of the study

The aim of the study was to examine the perceptions of the teaching profession, satisfaction with the choice of a study programme and the study programme itself, and desirable work values of students in their final year of teacher education studies; to determine if the above-mentioned characteristics with regard to the area of study and intentions to enter the teaching profession upon completing the studies differ, and to examine to what extent the mentioned factors predict the students' intention to enter the teaching profession upon completing their studies.

In line with the aim of the study, the following questions were posed:

1. Are there differences in the perceptions of the teaching profession, satisfaction with the study programme and desirable work values with regard to the field of study?

2. Are there differences in the perceptions of the teaching profession, satisfaction with the choice of the study programme, satisfaction with the study programme itself, and the desirable work values with regard to the intention of finding employment in school upon completing the studies?
3. Which factors (perception of the teaching profession, satisfaction with the choice of the study programme, satisfaction with the study programme itself, and desirable work values) account for the explanation of the intention to find employment in school upon completing the studies?

Methods

Participants and procedure

A total of 443 students in their final year of teacher education studies in the Republic of Croatia participated in the study. Potential outliers were identified based on absolute z-scores ≥ 3.29 , resulting in the exclusion of nine participants. The removal of these participants did not alter the main findings of the study. The final sample consisted of 434 participants, of whom 365 (84.1%) were female and 69 (15.9%) were male. The average age of the participants is 23 years ($M_{age} = 23.05$; $SD_{age} = 1.35$). As in a majority of teacher education studies it takes five years to earn a master's degree in a particular field, the participants in this study were only students in their fourth or fifth year of study. The sample comprised 274 (63.1%) students in their fourth year of integrated graduate studies or in their first year of graduate studies, and 160 (36.9%) students in their fifth year of integrated studies or in their second year of graduate studies. The greatest number of participants, 57.8% ($n = 251$), are involved in interdisciplinary studies, 13.6% ($n = 59$) in humanities, 13.6% ($n = 59$) STEM, and 15% ($n = 65$) in social studies. Most participants (77.4%; $n = 336$) enrolled into the faculty which was their primary choice, while 22.6% ($n = 98$) study at a teacher education faculty which was not their first choice. In Croatia, senior students in secondary school make a list of 10 study programmes according to their personal preferences, while the actual faculty enrolment depends on their results in the school-leaving exams, and, at some faculties, on additional entrance exams.

The study was conducted via an online questionnaire, during the regular teaching period at faculties. A QR code containing the link to an online questionnaire was sent to professors at teacher education faculties, and they distributed it to students during regular classes. Participation was voluntary and anonymous, in line with the research code and approved by the Ethics Committee of the Faculty of Teacher Education, University of Zagreb. Before filling out the questionnaire, the participants were informed that they could withdraw from the study at any time. It took about 10 minutes to fill out the questionnaire.

Measuring instruments

Sociodemographic questions included were used to collect data about participants' age, gender, year of study, the faculty and area of study, as well as the city in which they study, and the academic title they will earn upon graduation. In addition, the participants provided answers to two questions relating to their choice of a study programme (*When choosing your desired study programmes, was this study programme your first choice?*) and intention to work in their profession (*Do you plan to find employment in school when you graduate?*). The possible answers were: yes, no, and not sure.

The choice of a study programme. In order to examine the perceptions of the choice of a study programme, FIT-Choice Scale items were used (Watt and Richardson, 2007). The scale had already been translated into Croatian (Jugović et al., 2012) and two factors were extracted: Social dissuasion and Satisfaction with choice. Each factor consists of three items (e.g., *Did others influence you to consider careers other than teaching?*; *How satisfied are you with your choice of becoming a teacher?*). The participants assessed their answers on a five-point Likert-type scale, points ranging from 1 – *not at all* to 5 – *extremely*. Exploratory factor analysis was performed and, in line with the Kaiser-Guttman criterion, two factors were extracted with eigenvalue greater than 1, explaining 68.78% of variance. The obtained factor structure is in line with the original scale. The calculated internal reliability coefficients were $\alpha = .755$ for the first factor, and $\alpha = .765$ for the second factor.

Satisfaction with a study programme. Satisfaction with a study was measured using seven items, five of which were taken from the *Student Satisfaction Questionnaire* (Wong and Chapman, 2023) (e.g., *How satisfied are you with your study programme?*), while two items were added relating to overall satis-

faction with a study programme and education (e.g., *Do you consider that, upon completion of your studies, you will be fully qualified for independent work in school?*). The participants used assessment ranging from 1 – *not at all* to 5 – *extremely*. The performed exploratory factor analysis pointed to the single-factor solution, explaining 52.03% of variance. The factor reliability coefficient is $\alpha = .830$.

Perceptions of the teaching profession. 15 items taken from the *FIT-Choice Scale* (Watt and Richardson, 2007), that is, from its Croatian version (Jugović et al., 2012), were used to examine the perceptions of the teaching profession. The performed exploratory factor analysis extracted four factors: Social status, Salary, Expert career, and High demand. The Social status factor consists of 5 questions (e.g., *Do you believe teaching is perceived as a high-status occupation?*), the Salary factor consists of 3 questions (e.g., *Do you think teaching is well paid?*), the Expert career factor consists of 4 questions (e.g., *Do you think teaching requires high levels of expert knowledge?*), and the High demand factor consists of 3 questions (e.g., *Do you think teachers have a heavy workload?*). The participants assessed the questions on a five-point scale, ranging from 1 – *I strongly disagree* to 5 – *I strongly agree*. The four extracted factors explained 67.49% of variance. However, a simple single-factor structure which would match the original questionnaire was not obtained. Three questions had low factor saturation and were removed from the analysis. The obtained reliability coefficients had the following values: $\alpha = .789$; $\alpha = .883$; $\alpha = .883$; $\alpha = .612$. Since the obtained reliability coefficient $\alpha = .612$ for the High demand factor was lower than the recommended value of .70, the average inter-item correlation (AIIC) was calculated additionally. The obtained value .454 exceeds the normal recommended range, pointing to a high level of homogeneity among items. As Cronbach's alpha can underestimate reliability in shorter scales, and average AIIC is a more stable internal consistency indicator, it was justified to retain and interpret this factor (Streiner et al., 2024).

Desirable work values. The *Lyons Work Values Survey* (LWVS; Lyons, 2003, 2010) was used to examine the desirable work values. The survey contains 25 items which were translated into Croatian language and adapted to Croatian context. The survey measures four dimensions of the desirable work values: cognitive (includes characteristics such as diversity within the job, promotion prospects, a sense of achievement); instrumental (suitable working hours, job security, benefits, etc.); altruistic (good colleagues, helping people, entertaining environment, etc.), and prestige (authority, prestigious job, influence, etc.). The participants assessed the importance of each individual future job characteristic on a five-point scale, from 1 – *not important at all* to 5 – *extremely important*. The performed exploratory factor analysis extracted four factors, in line with the original survey, explaining 55.26% of variance. The obtained reliability coefficients had the following values: $\alpha = .859$; $\alpha = .818$; $\alpha = .797$; $\alpha = .684$. As reliability value for the prestige factor was slightly lower, the average inter-item correlation (AIIC) was calculated additionally, with value of .354, which points to a satisfactory item homogeneity and is a justification for retaining and interpreting this factor (Streiner et al., 2024).

Results

The results of the descriptive analysis of all variables are presented in Table 1. Regarding the intention to find employment in school, 65.9% of participants reported that they planned to find employment in school upon graduation, 9.4% did not plan to do so, while 24.7% were undecided. A full theoretical range was achieved in almost all variables, which indicates that participants with low and high values of the measured constructs were included in the sample. The social dissuasion dimension refers to a perception of being encouraged by one's environment to choose teacher education studies and is normally assessed as moderate, while satisfaction with a choice of a study programme and satisfaction with a study programme itself are, on average, above the theoretical centre of the scale. In the perceptions of the teaching profession, the lowest ranking was given to the social status and salary, while expert career and high demand ranked highest. Among the desirable work values, those that were given the highest ranking were the cognitive, altruistic, and instrumental dimensions, while the prestige dimension was given a more moderate ranking. The skewness and kurtosis values of the continuous study variables were within a range considered acceptable for the assumption of normality (Kline, 2011).

Table 1. Descriptive statistics of the variables ($N = 434$)

Variable	Theoretical range	Observed range	<i>M</i>	<i>SD</i>	Skewness	Kurtosis
Social dissuasion	1 - 5	1.00 – 5.00	2.61	0.96	0.465	-0.247
Satisfaction with the choice of a study programme	1 - 5	1.33 – 5.00	3.75	0.82	-0.561	-0.003
Satisfaction with a study programme	1 - 5	1.29 – 5.00	3.18	0.62	-0.493	0.589
Perceptions of the teaching profession						
social status	1 - 5	1.00 – 4.40	2.49	0.67	0.106	-0.208
salary	1 - 5	1.00 – 5.00	2.09	0.84	0.378	-0.445
expert career	1 - 5	2.67 – 5.00	4.42	0.48	-0.722	0.574
high demand	1 - 5	1.50 – 5.00	4.08	0.66	-0.514	0.349
Desirable work values						
cognitive	1 - 5	1.38 – 5.00	4.33	0.54	-1.079	1.965
instrumental	1 - 5	1.71 – 4.29	3.95	0.40	-1.740	2.030
altruistic	1 - 5	1.71 – 5.00	4.23	0.56	-0.868	1.032
prestige	1 - 5	1.50 – 5.00	3.55	0.71	0.011	-0.349

In order to examine whether there are statistically significant differences in student perceptions with regard to the area of study, the one-way analysis of variance (ANOVA) was conducted (Table 2). Given the unequal group sizes, the assumption of homogeneity of variances was assessed using Levene's test. For the variables for which the assumption of homogeneity of variances was met, the standard one-way ANOVA was conducted, whereas Welch's ANOVA was used when this assumption was violated. For post-hoc comparisons, Scheffé's test was applied following the standard ANOVA, while the Games–Howell test was used following Welch's ANOVA. To control the Type I error rate associated with multiple comparisons, the Bonferroni correction was applied. Thus, differences were considered statistically significant at $p < .0083$ for an overall significance level of .05 and at $p < .0017$ for an overall significance level of .01.

The post-hoc analysis revealed statistically significant differences in encouragement to choose the teaching profession, satisfaction with the choice of a study programme, and satisfaction with studies. Students in the STEM area report the highest level of encouragement from their environment to choose the teaching profession, while students in social studies report the lowest level. These two groups differed significantly (*Cohen's d* = 0.50), indicating a moderate effect size.

Students in the interdisciplinary studies seem to exhibit the highest level of satisfaction with the choice of a study programme, and differed significantly from students in the humanities (*Cohen's d* = 0.62), STEM (*Cohen's d* = 0.49) and social studies (*Cohen's d* = 0.45), with moderate effect sizes. In student satisfaction with the studies, a statistically significant difference was determined between the students in social studies and students in interdisciplinary areas (*Cohen's d* = 0.52), indicating a moderate effect size.

With regard to perceptions of the teaching profession, salary received the lowest overall rating. Students in the interdisciplinary areas reported the lowest rating of salary, and differed significantly from the students in humanities (*Cohen's d* = 0.66) and social studies (*Cohen's d* = 0.55). In addition, STEM students differ significantly from students in social studies (*Cohen's d* = 0.62). Although the perception of teacher status received a relatively low rating overall, students in social studies reported a slightly higher rating, than students in the STEM (*Cohen's d* = 0.86), interdisciplinary (*Cohen's d* = 0.81) and humanities (*Cohen's d* = 0.65) areas, with moderate to large effect sizes. When assessing the demands of the teaching profession, students in social studies reported the lowest rating, and differed significantly from

students in the interdisciplinary area (*Cohen's d* = 0.87), the humanities (*Cohen's d* = 0.76) and STEM (*Cohen's d* = 0.94). These differences corresponded to moderate to large effect sizes.

With regard to the desirable characteristics of the future profession, statistically significant overall differences were found for cognitive, instrumental, altruistic and prestigious characteristics, however, the overall effect sizes were small. For the cognitive characteristics and prestige, although the overall differences were statistically significant and associated with small effect sizes, the post-hoc analysis did not reveal statistically significant differences between any individual areas of study following the Bonferroni correction. Similarly, statistically significant overall differences with small effect sizes were found for instrumental characteristics (Welch's $F(3, 125.857) = 3.744, p = .013$) and altruistic characteristics (Welch's $F(3, 123.856) = 6.199, p = .001$). However, the post-hoc analysis did not reveal statistically significant differences between individual areas of study after applying the Bonferroni correction.

Table 2 . Differences in perceptions with regard to the area of study (N = 434)

Variable	Area of study								ANOVA F (3.430)	p	F Welch	p		η_p^2
	A		B		C		D							
	N = 251		N = 59		N = 59		N = 65							
	M	SD	M	SD	M	SD	M	SD						
Social dissuasion	2.64	0.92	2.46	0.94	2.96	1.05	2.31	0.94	5.455	.001*	/	/	C - D	.037
Satisfaction with the choice of a study programme	3.93	0.79	3.41	0.86	3.51	0.90	3.60	0.65	10.103	.001*	/	/	A – B, C, D	.066
Satisfaction with a study programme	3.09	0.64	3.31	0.61	3.19	0.53	3.40	0.52	5.438	.001*	/	/	A - D	.037
Perceptions of the teaching profession														
social status	2.41	0.65	2.50	0.65	2.37	0.67	2.91	0.60	11.322	.001**	/	/	D – A, B, C	.073
salary	1.94	0.80	2.42	0.92	1.98	0.75	2.47	0.81	11.036	.001**	/	/	A – B, D C - D	.071
expert career	4.41	0.49	4.44	0.42	4.51	0.50	4.35	0.49	1.324	.266	/	/	-	.009
high demand	4.17	0.63	4.10	0.64	4.19	0.56	3.59	0.71	15.327	.001**	/	/	D – A, B, C	.097
Desirable work values														
cognitive	4.42	0.51	4.24	0.53	4.23	0.51	4.18	0.63	6.091	.001	/	/	-	.035
instrumental	4.00	0.35	3.97	0.34	3.88	0.40	3.78	0.57	/	/	3.744	.013	-	.038
altruistic	4.33	0.49	4.10	0.62	4.11	0.55	4.05	0.69	/	/	6.199	.001*	-	.045
prestige	3.65	0.71	3.33	0.64	3.31	0.71	3.57	0.71	5.731	.001	/	/	-	.038

Note: * $p < .05$; ** $p < .01$

Group A – interdisciplinary area of study; B – humanistic area; C – STEM; D – social studies area

The following research task was to examine whether there were differences in the examined variables with regard to students' intentions to find employment in schools. Given the unequal group sizes, the assumption of homogeneity of variances was assessed using Levene's test. For the variables for which the assumption of homogeneity of variances was met, the standard one-way ANOVA was conducted, whereas Welch's ANOVA was used when this assumption was violated. For post-hoc comparisons, Scheffé's test was applied following the standard ANOVA, while the Games–Howell test was used following Welch's ANOVA. The analyses revealed statistically significant differences between the observed groups with regard to satisfaction with the chosen study programme, satisfaction with studies and in the assessment of the importance of individual desirable characteristics of future profession (Table 3).

Table 3. Differences in perceptions with regard to intentions to find employment in school (N = 434)

Variable	Employment intention						F (2.431)	p	F Welch	p		η_p^2
	A		B		C							
	N = 286		N = 41		N = 107							
	M	SD	M	SD	M	SD						
Social dissuasion	2.63	0.96	2.73	0.98	2.51	0.94	0.987	.374	/	/	-	.005
Satisfaction with the choice of a study programme	4.10	0.62	2.47	0.77	3.32	0.62	/	/	125.787	.001**	A-B, C	.412
Satisfaction with a study programme	3.25	0.56	2.87	0.79	3.12	0.64	/	/	5.461	.006*	A-B	.035
Perceptions of the teaching profession												
social status	2.49	0.66	2.49	0.72	2.48	0.67	0.014	.986	/	/	-	.000
salary	2.10	0.82	1.98	0.88	2.12	0.88	0.448	.639	/	/	-	.002
expert career	4.45	0.46	4.34	0.61	4.34	0.48	2.640	.073	/	/	-	.012
high demand	4.11	0.62	4.02	0.84	4.01	0.70	/	/	.916	.404	-	.005
Desirable work values												
cognitive	4.40	0.49	4.34	0.51	4.16	0.62	8.252	.001*	/	/	A - C	.037
instrumental	3.98	0.37	3.92	0.31	3.86	0.49	/	/	3.043	.052		.017
altruistic	3.60	0.70	3.55	0.77	3.40	0.72	3.101	.046	/	/		.014
prestige	4.31	0.53	4.02	0.71	4.08	0.54	9.743	.001*	/	/	A-B, C	.043

Note: * $p < .05$; ** $p < .01$

Group A – students who intend to find employment in school upon graduation; Group B – students who do not intend to find employment in school upon graduation; Group C – students who have not yet made a decision whether to find employment in school or not.

Statistically significant differences were found in the perceptions of satisfaction with the chosen study programme (Welch's $F(2, 96.895) = 125.787$, $p < .001$). Students who intend to find employment in schools upon completing their studies are more satisfied with their choice of the study programme than students who did not have such intentions (*Cohen's d* = 2.33) and those who were undecided (*Cohen's d* = 1.26), indicating very large effect sizes. Statistically significant differences were found in the perceptions of satisfaction with studies (Welch's $F(2, 93.426) = 5.461$, $p = .006$). Students who intend to find employment in schools upon completing their studies are more satisfied with their studies than students who do not intend to find employment in schools (*Cohen's d* = 0.56), indicating a moderate effect size. Students who intend to find employment in school differed statistically significantly from undecided students in their assessment of the importance of desirable characteristics of their future profession (*Cohen's d* = 0.44), indicating a small effect size. Regarding the importance of prestige, students who intend to find employment in school differed statistically significantly from those who do not have such intentions (*Cohen's d* = 0.46) and those who are undecided (*Cohen's d* = 0.42), whereby small effect sizes were determined as well. No statistically significant differences were found for the remaining examined variables between the observed groups according to the applied criterion of statistical significance.

The following research task was to determine the extent to which the examined variables contribute to students' intentions to find employment in school. The multinomial logistic regression was employed for data analysis (Table 4), as the criterion variable comprised three categories. The "yes" category was used as the reference category, and the model estimated the likelihood of being in the "no" and "undecided" categories relative to the "yes" category. The regression model was statistically significant, $\chi^2(26) = 245.52$; $p < 0.01$. Goodness-of-fit tests indicate a satisfactory fit of the model to the data. Neither the Likelihood Ratio Test, $\chi^2(840) = 864.10$; $p > 0.05$, nor Pearson's test, $\chi^2(840) = 486.16$; $p > 0.05$ were statistically significant. To assess the goodness of fit of the multinomial logistic regression model, three standard pseudo- R^2 measures were examined: the Cox and Snell, Nagelkerke's and McFadden's R^2 . The Cox and Snell R^2 was .432, Nagelkerke's R^2 was .530, and McFadden's .336, indicating a satisfactory model fit and an improvement over the intercept-only model. The Likelihood Ratio Tests showed that only satisfaction with the choice of a study programme ($\chi^2 = 182.49$, $p < .001$) and cognitive work values ($\chi^2 =$

6.93, $p = .031$) made statistically significant contributions to the model. None of the remaining predictors significantly improved model fit (all $p > .05$). The model correctly classified 74.0% of the cases overall. Classification accuracy was highest for students intending to work in schools (91.3%), followed by those not intending to work in schools (61.0%), whereas prediction accuracy was considerably lower for undecided students (32.7%). Multicollinearity diagnostics indicated no evidence of problematic multicollinearity among the predictors. Tolerance values ranged from .540 to .913, while Variance Inflation Factor (VIF) values ranged from 1.095 to 1.853.

Table 4. Results of multinomial logistic regression predicting employment intention

Variable	no vs. yes			undecided vs. yes		
	<i>Exp(B)</i>	95% CI	p	<i>Exp(B)</i>	95% CI	p
gender	0.27	0.09 – 0.86	.026	0.66	0.33 – 1.31	.235
first choice	0.75	0.25 – 2.26	.612	1.09	0.58 – 2.07	.779
Social dissuasion	1.16	0.70 – 1.92	.568	0.85	0.64 – 1.13	.272
Satisfaction with the choice of a study programme	0.01	0.01 – 0.03	.001*	0.13	0.08 – 0.22	.001*
Satisfaction with a study programme and its quality	1.34	0.58 – 3.13	.493	1.26	0.75 – 2.09	.381
Salary	1.28	0.69 – 2.40	.432	1.13	0.79 – 1.61	.494
High demand	0.66	0.32 – 1.37	.267	0.88	0.56 – 1.38	.587
Status	2.28	1.01 – 5.17	.047	1.13	0.81 – 2.11	.264
Expert career	1.55	0.55 – 4.38	.412	1.16	0.60 – 2.23	.666
Cognitive work values	4.07	0.86 – 19.13	.076	0.72	0.30 – 1.76	.477
Instrumental work values	1.09	0.20 – 5.77	.921	1.29	0.53 – 3.16	.570
Altruistic work values	0.73	0.25 – 2.17	.473	1.04	0.52 – 2.11	.902
Prestige	0.43	0.18 – 1.04	.062	0.69	0.42 – 1.14	.153

Note. The reference category for the criterion variable was “yes”. OR = odds ratio; CI = confidence interval.

Estimates of the individual parameters are presented in Table 4. For the “no” category, relative to the “yes” reference category, satisfaction with the choice of a study programme was statistically significantly associated with students’ intentions of finding employment in school. An odds ratio (OR) below 1 indicates that higher satisfaction with the choice of a study programme was associated with a lower likelihood of being in the “no” category relative to the “yes” category. In this comparison, gender and perceived status of the teaching profession were also statistically significant predictors. For the “undecided” category relative to the “yes” reference category, satisfaction with the choice of a study programme was likewise statistically significantly associated with the students’ intentions of finding employment in school. As satisfaction with the choice of a study programme increases, the likelihood of being in the “undecided” category decreased relative to the “yes” category. None of the other individual predictors reached statistical significance in this comparison.

Overall, the multinomial logistic regression results indicate that satisfaction with the choice of a study programme was the most consistent predictor of students’ intentions of finding employment in school. A higher level of satisfaction with the choice of a study programme was associated with lower likelihood of indecisiveness or the intention not to find employment in school in reference to employment intentions. Gender and perceived status of the teaching profession were statistically significant only in the comparison between the “no” and “yes” categories, whereas the other examined predictors did not make statistically significant contributions to these comparisons.

Discussions

This research provides an insight into perceptions of various dimensions of the teaching profession in students. Students assessed lowest the salary and social status dimensions of the teaching profession. This is not surprising, as many researchers have pointed to low perceptions of the teaching profession with regard to their salary and social status in a majority of countries (e.g., [Lehtinen et al., 2025](#); [Watt and](#)

Richardson, 2012), which eventually results in a low status of this profession on a global scale (la Velle, 2019). Although there have been efforts to acknowledge teaching as a profession and to assign it a high social status, it still largely remains a semi-professional occupation (Hargreaves and Flutter, 2019). Furthermore, a relatively low assessment of the social dissuasion factor indicates that participants were not influenced to a great extent by other people in their environment to consider choosing a different career instead of the teaching career. It can be assumed that they had autonomy when they were choosing their future profession. The findings obtained in other studies indicate that the choice of the future profession is significantly influenced by the relationships with peers and parents (Owusu et al., 2021; Suryani and George, 2021). Contrary to that, a high assessment of the perception of the expert career dimension reveals that students frequently associate the teaching profession with a high level of expert and content knowledge, as well as with a wide range of professional skills, mostly those relating to teaching, demonstration, and communication. A similar pattern was detected by Puklek Levpušček and Depolli Steiner (2024), whose findings show that students in Slovenia give a high ranking to the teachers' expertise, but a lower ranking to their social status and the material component of the teaching profession, which reflects imbalance between the demands and reward in the teaching profession.

Within this first research question, we analysed the differences in the perceptions of the teaching profession, satisfaction with a study programme and desirable work values with regard to the area of study. The obtained findings point to several patterns which enable a deeper understanding of student attitudes to the teaching profession. It has been shown that there are no significant differences in the perceptions of the expert career between students in different areas of study, which suggests that expertise is considered a universal and an unquestionable value. In addition, differences were detected neither in the perceptions of the cognitive dimension of the desirable future job nor in the importance of prestige in the future job. It is interesting to note that students in the STEM area believe that they were encouraged to choose the teacher education studies the most, in which they differ from students in the social studies area. Such result is indicative because in Croatia, as in other parts of the world, students are less likely to opt for teacher education studies within the STEM area, which eventually results in a lack of qualified teachers in schools (Domović i Drvodelić, 2025). As for the students in the disciplinary studies, who are primary teacher education students, they seem to be most satisfied with the choice of a study programme and significantly differ from students in humanities, social and STEM areas. The reason for that is that primary education teachers' employment prospects are relatively limited to primary school. Students are aware of this fact, and those who enrol in the primary teacher education studies already know what their future job will be, unlike students in other areas of study who have more employment prospects upon completing their studies. At the same time, students in interdisciplinary studies are least satisfied with their study programme. Gibson (2010) points out that the most powerful factors which affect student perceptions of the overall satisfaction with a study programme are: the quality of teaching, the skills and knowledge gained, and the curriculum. There are also many non-academic factors, such as students' feeling of belonging and the perception of responsibility and care of the educational institution for its students. Wong and Chapman (2023) found that informal interaction between students is significantly associated with satisfaction in all of the three examined aspects – academic, institutional, and student life at university. Since numerous factors can have an impact on the satisfaction with a study, it is necessary to carry out more research in order to identify the reason for such assessment. Regarding the desirable work values, students in interdisciplinary studies give the highest ranking to all dimensions, including prestige. This indicates that they are developing a clear and positive professional image of the teaching profession and that they are aware of the high demands and social status of their future job, which can reflect their previous professional orientation and focus on the future employment in primary school.

Within the second research question, we examined the differences in the perceptions of the teaching career, satisfaction with the choice of a study programme, satisfaction with the study programme, and desirable work values, with regard to the intention to find employment in school upon completing the studies. About two-thirds of participants intend to find employment in school, but one-third of students, although they have enrolled into teacher education studies, either do not intend to or are not sure if they would find employment in school. The obtained findings indicate that the intention to find employment in school is an important differentiating factor in perceiving the study programme and the teaching profession. The students who intend to work in school upon completing their studies show a higher level of satisfaction with their choice of a study programme and overall study experience, and have a more posi-

tive perception of the cognitive demands and social status. It should be pointed out that the intention of finding employment in school is most profoundly influenced by the choice of a study programme, which has been expected, as these students' professional aspirations relating to the study programme and future employment coincide. Such results suggest that positive professional orientation during the course of study contributes to a higher sense of purpose and value of the chosen educational path. Similar patterns have been noticed in international research. For example, [Rones and Smith \(2009\)](#) claim that a significant number of students in teacher education studies in Norway express insecurity about entering the teaching profession, which proves that professional decision about entering the teaching profession is not always stable or simple. An integrative literature review conducted by [Thomas Dotta et al. \(2025\)](#) shows that the teaching profession is still appealing to candidates motivated by intrinsic reasons and social usefulness, but that external factors such as low salary, demanding working conditions and limited promotion prospects are huge obstacles. In addition, [Wang et al. \(2022\)](#) found that teacher education students in Scotland often exhibit ambivalent attitudes to choosing the teaching career, acknowledging on the one hand professional fulfilment and social value of the profession, and emphasizing the negative aspects associated with workload, stress, salary, and social status on the other. In line with that, the findings of this study can be interpreted in a broader context of global trends which point to a complex relationship between professional ideals and real working conditions in the teaching profession.

With regard to the third research question, we tried to determine the factors important for explaining the intention to find employment in school upon completing the studies. Although satisfaction with the choice of a study programme and cognitive work values significantly contribute to the logistic regression model, the obtained results indicate that the satisfaction with the choice of a study programme variable is the only variable statistically significantly associated with the intention of finding employment in the teaching profession. The cognitive work characteristics relating to professional growth, goal achievement and overcoming intellectual challenges are important for all three groups of participants (those who intend to find employment in school, the undecided participants, and those who do not intend to work in school), but are not critical. In other words, the students who are satisfied with choosing teacher education studies are more likely to plan to find employment in school. This finding confirms the importance of early satisfaction with the chosen profession and identification with the chosen study programme as key factors in the process of shaping professional intentions. A positive experience throughout the study may increase the inclination to the teaching profession, while dissatisfaction or doubts regarding the choice of a study may result in a lower level of interest for continuing the teaching career. Contrary to the expectations, the perceptions of salary, social status, high demands of working in school or the prestige related to the teaching profession have not proved to be significant for the intention to find employment in school. This finding suggests that the decision to stay in the profession does not solely depend on the external or material factors but also on intrinsic motivation and satisfaction with one's professional choice.

In brief, we identified various dimensions of choice and employment in the teaching profession which Croatian teacher education students perceive as significant, depending on the area of study and their intentions of finding employment in school upon graduating from university. Unlike numerous other studies emphasizing the importance of social, material or individual factors for finding employment in the teaching profession (e.g., [Dündar, 2014](#); [OECD, 2018](#); [Pavin Ivanec, 2020](#); [Sutcher et al., 2019](#)), this study has shown that the choice of a study programme is of crucial importance for the intention of finding employment in school. Research on motivation for teaching is frequently focused only on the individuals who have already decided to enter the teaching profession ([See et al., 2022](#)). The current findings contribute to the literature by suggesting that research should encompass the population of high school students who have not yet made such a decision.

Conclusions

A high social status associated with the teaching profession is of key importance for the entire society. Lately, more and more attention has been paid to teacher shortage at all levels of education, both in Croatia and around the world. However, most research has been focused on the teachers who found job in the teaching profession and on their plans to stay in or leave school, or on the teachers who abandoned the teaching profession and the reasons leading to such a decision. Since the trend to give up the intention of finding employment in the teaching profession has been noted in teacher education students, the aim of this study was to examine the perceptions of the teaching profession, satisfaction with the choice of a study programme,

satisfaction with a study programme, and desirable work values in students in their final year of study.

The findings indicate that there are differences in a majority of the examined variables with regard to the area of study, which is important to take into consideration when designing educational policies and strategies for attracting student teachers. It has been specially pointed out that satisfaction with the choice of a study programme is crucial for the intention to find employment in the teaching profession. This finding suggests the importance of strengthening professional orientation and providing support to students during their studies in order to help them identify with the teaching profession. Future research should be focused on a more thorough examination of satisfaction with the choice of a study programme construct, which could be multidimensional and associated with a range of personal and contextual factors. In order to prevent teacher shortage, which is already present in Croatia, primarily in the STEM area, it is necessary to act systematically and meaningfully at the national level to increase interest in enrolling into teacher education faculties.

However, the study has certain limitations. Although students from all Croatian universities participated in the study, the sample is not representative, so the generalization of the findings should be done with caution. A cross-sectional study design does not facilitate drawing conclusions on causal relationships nor monitoring the changes in the employment intentions throughout a certain time period. Secondly, the research was based on the data collected based on self-assessment, which may have involved certain bias in the answers provided by the participants. Thirdly, the gender structure was unequal, as female students made up a majority of the sample, which may limit the possibility of generalizing the results. Finally, the expressed intention of finding employment in school does not have to necessarily result in the actual decisions on employment upon completing the studies. Future longitudinal research might therefore examine if the employment intentions change over time and to what extent they reflect the actual professional choices.

Despite the limitations, the findings of this study contribute to a better understanding of the student teachers' perceptions of professional and career perspectives and can be taken as a basis for shaping the measures which would encourage greater interest for the teaching profession and contribute to its better social status. The obtained results enable practical insights which may be considered a starting point in designing a systematic, comprehensive and long-term solution at the national level which would, taking into account the quality and the status of the teaching profession, include creating high-quality teacher education study programmes and a policy for attracting, employing and retaining teachers in the teaching profession.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Institutional Review Board Statement

This study was conducted according to the ethical standards of the University of Zagreb Faculty of Teacher Education (251-378-01-25-2).

Author Contributions

Conceptualization, T.V., I.K., and M.Đ.; methodology, T.V.; formal analysis, T.V., I.K., and M.Đ.; writing—original draft preparation, T.V., I.K., and M.Đ.; writing—review and editing, T.V., I.K., and M.Đ.; funding acquisition, T.V.; supervision, T.V. All authors have read and agreed to the published version of the manuscript.

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Cognitive Overload and its Plausibility in Impairing the Academic Performance of Professors in State-run Universities – A Qualitative Study in Indian Microenvironment

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Abstract: In this qualitative study, I analysed the magnitude of cognitive overload among professors employed in Indian state-run universities and its impairment of their academic performance. The research was conducted in the Indian higher education framework, where the ever-increasing cognitive overload has significantly impacted academic performance and role expectations of professors. This qualitative study examines the causes of cognitive overload among professors at state-run universities, as well as its impact on their academic performance. This study offers a clearer understanding aimed at establishing cognitive overload as an obstacle to work efficiency within the Indian micro-environment. Semi-structured interviews were conducted with 40 assistant professors, associate professors and professors working at 20 state-run universities in India. The collected data were then examined thematically. Seven interrelated themes surfaced: (1) Task switching and interruptions - continuous juggling between tasks; (2) Pedagogical impact - effects on teaching quality; (3) cognitive symptoms - difficulty in thinking and understanding; (4) Social symptoms - difficulty in interaction and collaboration; (5) Behavioural manifestations - altering behavioural patterns; (6) Physical and emotional toll - complete physical and mental exhaustion and (7) Coping and support - dealing with the problem and assistance. These themes were persistently mirrored across participants, indicating robust data saturation. The study provides insights on the challenges faced by professors in managing their job-related responsibilities in the context of rising cognitive load arising from the administrative setup of Indian universities. The study reveals the impact of cognitive overload on the effectiveness of academic and research performance of Indian professors.

Keywords: Cognitive Overload, Academic Performance, State-run Universities, Task Switching, Pedagogical Impact, Cognitive and Social Symptoms, Behavioral Manifestations, Coping and Support.

Introduction

In recent decades, the demand for higher education in India has increased rapidly, especially from groups that have traditionally been left behind or excluded from educational networks. This has put already tightened governments under enormous pressure to provide support to their endeavour of imparting quality education to all (Bhatty et al., 2022). Higher education in India is principally administered by the state-run education network, which is controlled by the government at the central, state, and local levels (Robert, 2021). The current state of the teaching profession in state universities in India is experiencing a profound contradiction. While new reforms are being implemented to bring transparency and improve teacher welfare, the profession is facing a serious crisis due to the increasing reliance on contractual and guest faculty (Takker and Ramchand, 2022).

Professors are the second most important human resources at universities after students, and the quality of their teaching has an impact not only on the quality of their educational guidance services but also on their career guidance. However, upon entering the teaching profession, new professors often find that they lack the exposure, expertise, and ability to empathize with students. In some cases, they may

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not be able to adapt quickly to changes in their role expectations and be unable to meet the teaching and mentoring needs (Narayanan et al., 2025). In a typical state-run university in India factors such as high teaching loads, large class sizes, multiple modalities, diversity in student learning needs and curriculum updates particularly after the implementation of NEP-2020 etc are giving rise to cognitive overload among professors (Apat and Swain, 2023).

Cognitive overload is defined as a psychological condition that arises when the volume of information or the number of concurrent tasks outpaces the capacity of a person's working memory. In such a state, our brain turns "saturated", making it tough to productively process, understand or hold on to new information (Krish, 2000; Jaeggi et al., 2007; Pace et al., 2021; Lahlou, 2025). Cognitive overload relates to the openness of people to massive amount of information that has a comprehensive meaning. More specifically, it can interfere with information processing and decision-making abilities (Bolisani et al., 2018). Cognitive overload implies to a state of affairs in which the processing demands involved in a task may surpass the processing capability of the cognitive system (Mayer and Moreno, 2003). Accordingly, it reflects the inability of an individual to demonstrate problem-solving capability or make decisions due to severe cognitive processing limitations. To study the impact of cognitive overload on professors is of great importance as it relates to pertinent outcomes like job satisfaction, quality of student progression and overall academic performance. It can sizeably affect the quality of life of professors alongside the teaching quality and academic upliftment of the future workforce.

Cognitive overload has much to do with many of our intellectual problems. Professors today have a multitude of tasks and responsibilities, so much so that multitasking has become a way of life. Information is perpetually forced upon professors, and regardless of how much information is received, they feel that more is needed, and of reasonable standard and distinctness. The universities need to help address these issues. But the means and efforts remain deficient (Martini et al., 2019; Rodríguez, 2011). In a typical setting today, professors in universities have to perform multiple roles like that of a teacher, examiner, researcher and administrator and mentor. A satisfactory performance of all these roles requires continual overhauling of information processing on his end, thereby giving rise to cognitive overload (García-Arroyo and Segovia, 2019). The overall implication of cognitive overload on university professors is serious. When the compulsions of teaching, research, publications, and administrative tasks intersect simultaneously, the brain's information processing capacity begins to collapse. This makes it difficult to maintain focus, reduces decision-making ability, and reduces creativity. As a result, professors face hardships in attaining academic excellence, producing high-quality research papers and often fail when trying to apply creative teaching pedagogies in their classrooms (García-Arroyo and Segovia, 2019). Constant mental fatigue increases stress, which reduces productivity in general and creates a profound sense of discontent with academic endeavours.

In the current study the researcher has made an attempt to comprehend the implication of cognitive overload on task related performance of professors teaching in various state-run universities across northern India. The research has been carried out by conducting a qualitative study through focused interviews of 40 assistant professors, associate professors and professors working across twenty state-run universities. The target audience of participants are the professors who are actively employed as permanent/regular teaching faculties in various academic streams like humanities, sciences, commerce, management, engineering, medical science, linguistics, agricultural science, music and law and are also discharging administrative assignments simultaneously at a state-run university in India. Therefore, there are certain fundamental questions concerned with cognitive overload among professors which the researcher thinks are worth considering:

1. How does regular task switching and interruptions affect the state of cognitive overload among Indian professors?
2. How do Indian professors subjectively perceive and explain the manifestations of pedagogy, cognition, behaviour, emotions social relations on their cognitive overload?
3. What coping strategies do Indian professors use to manage cognitive overload for maintaining their professional performance?

The answers to the above questions should enlighten social science researchers who prepare surveys on cognitive overload of professors. Expanding the knowledge of cognitive overload can help researchers build models by analysing trends collected. This will enable professors to develop more effective

tive strategies to optimize the performance for attaining professional distinction. This study investigates the current state of cognitive overload among professors in India and its potential impact on academic performance, thereby enhancing the standard of professional assignments delivered by the academicians. The existing literature lacks empirical research on the level of cognitive overload among university professors. In light of recent regulatory developments in India like National Educational Policy-2020 rollout, the viewpoint of professors on cognitive overload requires further study to upgrade academic and overall professional performance. Thus, the objective of this research is to delineate the factors and impact of cognitive overload from the standpoint of state-run university professors, to achieve desirable academic performance.

Theoretical Foundation

This paper is based on the notion of Cognitive Load Theory propounded by Sweller (2011) that differentiates three kinds of cognitive load:

- Intrinsic cognitive load – It is related to the intrinsic complicatedness of the material under process. In a typical university setting, this coincides with the innate cognitive stipulations of teaching, research and executive decision making.
- Extraneous cognitive load – It is the load created by the way information is dispensed or by the processes surrounding a task. This implies administrative procedures, meeting arrangements, accreditation paperwork and university workflows that introduce needless cognitive load to the deep-rooted complexness of the activity.
- Germane cognitive load – The cognitive load associated with filtering, learning, and purposeful obligation. For university professors, this is about the intellectual resources that are engaged in contemplative teaching, innovative research, and scholarly reasoning.

As stated by Sweller, cognitive overload is the result of the total intrinsic and extraneous load exceeding the dimensions of an individual's functional memory, leaving inadequate supplies for germane processing. Cognitive overload for university professors occurs when the mingling of complicated academic activities (intrinsic) and burdensome administrative processes (extraneous) exceeds cognitive capability and hinders worthwhile participation in teaching and research (germane).

Kirsh's (2000) supporting framework additionally emphasizes that cognitive overload extends beyond the mere accumulation of facts and encompasses the configuration, timeliness and feasibility of the flow of information. This perspective is particularly important for professors who have to deal with many demands at the same time and are constantly interrupted.

Methodology

Study design

This is a qualitative interview-based study that focuses on the awareness of cognitive overload and its potential impact on academic performance among professors currently teaching in various public universities in North India. A detailed review of the literature indicates that there exists no detailed literature identifying patterns of teacher cognitive overload in the Indian context. Therefore, the qualitative research methodology through semi-structured interviews is appropriate for gaining new knowledge about the effects of cognitive overload. Semi-structured interviews are the most suitable method for collecting primary data because open-ended questions allow the researcher to procure complete details and gain a deeper comprehension of the subject.

Operationalization of cognitive overload

The author operationalised cognitive overload using a multilayered structure advanced by Sweller (2011) and Kirsh (2000) for conducting this qualitative research. Cognitive overload in data capturing and data interpretation was recognized by the researcher based on the following four interpretive benchmarks:

- (i) Functional memory saturation – periods when participants reported incompetency in processing, retaining or recalling information while managing multiple coinciding activities. This was differentiated from normal workload in that it focused on handling collapses rather than the magnitude of activity.

- (ii) Task switching cost – specific proof of performance deterioration (e.g. zoning out, problems in re-claiming attention, fumbles) when moving between pedagogical and executive tasks. The focus was on the standard of cognitive execution, not the quantity of tasks.
- (iii) Personal cognitive stress – self-assessed mental exhaustion, concentration hurdles, and decreased decision-making capability specifically related to information filtering demands in opposition to behavioural or motivational objections.
- (iv) Information processing deficit – self-reported inability to categorize or reject immaterial information, resulting in a sense of cognitive “saturation” that hindered academic obligations.

The study meticulously separated cognitive overload from job-related stress, burnout and normal workload:

- Occupational strain was coded if respondents reported anxiety, stress or mental stimulation without explicit cognitive processing defaults.
- Burnout was coded when respondents reported emotional fatigue, dissociation or decreased professional efficiency, irrespective of cognitive execution.
- Normal workload was coded when respondents mentioned task magnitude or time constraint but were still cognitively functioning without any stated memory or distraction issues.

Data were construed as cognitive overload solely when respondents expressly connected their problems to information handling restrictions (e.g. lapse in memory, ‘mind blanking’, inability to pursue conversations). This systematic differentiation is presented in Table 1 below:

Table 1. Distinction between cognitive overload and other associated constructs

Construct	Fundamental Indicators	Distinction from Cognitive Overload
Cognitive Overload	Loss of memory, difficulty in concentration, reduced ability to process information, impaired decision making.	Emphasis on cognitive capability overloaded by filtering demands
Occupational Stress	Anxiety, stress, mental stimulation, concern	Devoid of the explicit cognitive-processing default element
Burnout	Emotional fatigue, dissociation, curtailed personal achievement	Behavioural/emotional decline as opposed to cognitive saturation
Natural Workload	Time constraint, task magnitude, work pressure	Not necessarily beyond cognitive processing capability; can be handled

Participant selection

The interviewees selected for the study are assistant professors, associate professors and professors working across 20 universities run by the Central Government of India and other state governments of various states of North India. The researcher utilised his professional connections, developed during 10 years of service at a State-run University of Uttar Pradesh (the largest Indian province in terms of population and number of universities). After the professors were interviewed, the researcher asked the professors to share recommendations from their academic networks about who would be the best fit for this study. There were also referrals from professors who refused to participate in the study. The main inclusion criteria were that professors must be employed as permanent/regular faculty members at public universities and must hold at least one non-academic portfolio at their respective universities. Few professors openly stated that they were unable to answer interview questions because of their reluctance/hesitation to participate in the research. Some professors directly emphasized that the opinions expressed reflected their personal worldviews developed during their time at the university and did not necessarily align with the university in which they worked. All of the professors interviewed requested personal and institutional anonymity, which is understandable. Some of the referrals pertained to those professors who had already retired from a university department and therefore could not qualify to be a part of the research.

Sampling method

The researcher has used chain-referral sampling also known as snowball sampling to select participants from various universities with the aim of developing an understanding on the subject matter through

real-time experiencers, from distinctive viewpoints and dynamics. Snowball sampling is a widespread sampling technique mainly used for approaching the covered inner circle and the classes basically found far away from the conventional researches in social sciences (Atkinson and Flint, 2001). The chain-referral or snowball sampling was of immense help in getting referrals from the interviewed professors to further approach more professors. The rationale behind the use of chain-referral sampling was to gain access to such professors who hold expertise in the relevant domain, these included professors particularly from different academic disciplines right from humanities, science, social sciences and commerce who had a sizeable experience in terms of working in the administrative domain alongside their regular teaching assignments. The respondent professors were employed across different universities holding key administrative positions like Head of the department, Dean of the faculty, Course coordinators, Committee conveners/members, Proctor, Warden etc.

Sampling size

This study has been finalized with a sample size of 40 professors, almost all of these professors are employed in state-run universities as head of department, dean of faculty, course coordinators, among others. The fundamental premise of qualitative research is that it is based on the study of phenomena rather than numbers of responses. Comparing the response rates of quantitative studies to qualitative studies is not regarded as reasonable and does not save time. This study is highly insistent, interactive and reiterative. Every single interview was cautiously examined until the point at which fresh patterns ceased to emerge in the responses. This was the point at which the researcher resolved to wind up further interviews. This is called saturation i.e., the procedure of conducting a series of interviews, one after another, usually with different respondents until all concepts begin to appear multiple times during the interview without any new concepts emerging (Trotter II, 2012).

Collection of Data

The discussion with professors were conducted primarily over video calls, physical interactions and telephone. The interviews were conducted in a cost-effective manner and at the convenience of the concerned professor. The researcher made an attempt to incorporate questions that would provide assistance in finding the pertinent information which was needed to reach the eventual conclusion. Every interactive session was carried out for a mean time-span of 29.22 minutes. The actual duration of each session is specified at a later stage in the research paper. A time tracker was utilized by the researcher in order to document the exact time consumed in all the interviews. The researcher went ahead with seven semi-structured questions which were asked for organizing the interviews. The physical interviews were administered in the cities of Varanasi, Lucknow and Siddharth Nagar while video call-based interviews and over the telephone interviews were organized from cities like Kanpur, Ayodhya and Gorakhpur. To start with, the researcher introduced himself to the professors, a small introduction of the interviewee professor was also pursued, accompanied by the objective of the research which was elucidated to the professors. The interviews were conducted only after the objective of this research was comprehended and consented to.

Analysis of Data

As the purpose of this study is to get a deeper understanding of the experiences and perceptions of professors, qualitative content analysis is considered as a method of data analysis as it can furnish invaluable insights through the analysis of texts in detail. In qualitative data analysis, a researcher has the alternative to carry out the same methods used in quantitative studies as well (Bhatia et al., 2020). High quality content analysis does not refute a hypothesis, but aims to develop hypotheses for prospective quantitative studies. Content analysis is only useful if it is outlined systematically and clearly (Elo and Kyngäs, 2008). Latent analysis is executed on raw data accumulated during the interview to extract purposeful inferences.

This study takes into consideration two significant stages of qualitative content analysis which are data synthesis and data structuring. The primary step consisted of transcribing each interview and integrating the data, which decreases the risk of omissions. The secondary step consisted of an orderly qualitative content analysis of the professors' remarks on research questions. This is followed by coding and classification to identify broad themes such as task switching and interruptions, pedagogical impact, cognitive symptoms,

social manifestations, behavioural manifestations, physical and emotional toll and coping and support.

According to our analysis, major thematic areas and topics related to cognitive overload and academic performance emerged during the 34th interview. Redundancy began to step into the response at this point, and was hardly ever ascertained after that. It is satisfactory to draw out that approximately 85% of the factors connected to cognitive overload that can negatively affect academic performance were discovered during the 35th interview. Therefore, the study was conceptually based and deductive.

Diligence

This study was carried out by me as the sole author, an assistant professor at a state-run university in India (the opinions articulated by the author are the outcome of research and personal worldviews advanced during his work at the university, and do not inevitably correspond with the university in which he works). The complete research is segregated into multiple parts, and its maintenance is the sole responsibility of the author. The interview process began with a succinct introduction of the faculty member who participated in the interview process. All data was transcribed by the author. All activities, including faculty searches, scheduling faculty interviews, developing semi-structured questionnaires, and literature reviews, were performed solely by the author. It also required considerable meetings with fellow experienced researchers which usually persisted for some minutes to even an hour.

Ethical Implications

Participants voluntarily confirmed their participation by replying to the messages sent to them by the researcher on platforms like WhatsApp, e-mail, or LinkedIn. This research is neither listed at any place nor has been appraised by an institutional ethics committee. Confidentiality of the study is maintained by destroying all audio recordings post-decryption of the data considering its sensitivity and potential ramifications for the respondents. Moreover, this was also done anonymously. In all the data presented in this study efforts have been made by the researcher to maintain confidentiality by giving indicative introduction of various universities where the participant professors are currently employed and their explicit or implied relationship with cognitive overload.

Findings

Since the brain's working memory capacity is limited and the sheer amount of available information is quite large many teaching faculties across the globe are susceptible towards cognitive overload. Post experiencing unsettling circumstances teaching faculties in higher education may choose sub-optimal alternative which actually is heuristic streamlining. According to [Sweller \(2011\)](#), cognitive overload represents a state of affairs where the demands laid down on the working memory transcends its already bounded dimension, obstructing information filtering and learning.

Table 2 presents the questions developed during the interviews. Considering the opinion-based complexion of the subject matter under exploration and keeping in view that the objective of the investigation is significantly probative, the comprehension of participant insight and supplementary qualitative details were favoured than the sole study of quantitative data. At the end of each interview the findings were compiled and studied. The transcripts were cautiously analysed by the researcher for identifying patterns and drawing conclusions.

Table 2. Theme based semi-structured questions for interview

No.	Theme	Questions
1	Task switching and interruptions	Do you find it difficult to regain your concentration after being interrupted by non-academic tasks like attendance, committee work, administrative chores, accreditation planning and event planning?
2	Pedagogical impact	Have you recently delivered a lecture where you felt you were just “going through the motions” rather than deeply engaging with students because your mind was preoccupied with pending administrative deadlines?
3	Cognitive symptoms	Do you walk into a classroom or office and forget what you were about to do because your mind was processing too many other tasks?
4	Social manifestations	Do you avoid taking on new and interesting academic projects like new research collaborations simply because you feel too “mentally full” to handle them?
5	Behavioural manifestations	Have you noticed yourself becoming short-tempered or less patient with students or colleagues when you are under a high volume of simultaneous demands?
6	Physical and emotional toll	Do you experience physical symptoms like headaches, eye strain or fatigue specifically linked to days with high administrative or grading loads?
7	Coping and support	Is there a formal or informal support system within your university that helps you manage overwhelming workloads? If not so, where do you currently “offload” your tasks?

Table 3 gives the demographic characteristics of all the respondents participating in the study. The transcripts from the study which were analysed, encompassed 40 interviews with 21 assistant professors, 12 associate professors and seven professors working across 20 state-run university of India. Thirty-one respondents (77.5%) were men while nine respondents (22.5%) were women. Respondents reported a mean $\pm$ standard deviation of 8.00 ± 6.54 years of university teaching experience.

Table 3. Demographics of the professors participating in the interview

Attributes	Figure
Age	
25-35	03
35-45	12
45-55	15
55-65	10
Gender	
Male	31
Female	09
Experience	
0-10 years	16
10-20 years	15
20-30 years	07
30-40 years	02
>40 years	00
Current position	
Assistant Professor	21
Associate Professor	12
Professor	07
Number of administrative portfolios being held	
0-1	19
1-2	11
2-3	06

Attributes	Figure
3-4	03
>4	01
Administrative portfolio wise distribution (Assistant Professor/ Associate Professor/ Professor)	
Dean of Faculty	04
Head of Department	09
Course Coordinator	11
Director/Coordinator – Internal Quality Assurance Cell (IQAC)	03
Chief Proctor	02
Hostel Warden	05
Controller of Examinations	03
Faculty Incharge – University Guest House	01
Member – Admission / Examination Committee	14
Member – Departmental Research Committee	12
Member – National Assessment and Accreditation Council (NAAC) / National Institution Ranking Framework (NIRF) Committee	15

Table 4 presents particulars about the interviewed professors and the universities they are currently working at (names of the universities have not been disclosed as per the requests of the respondents), and the scheduled dates for each interview. The interviews took place over a six-month period, from September 2025 to February 2026. The researcher has strictly tried to maintain the confidentiality of all respondents. In fact, at the very outset of the interview the researcher informed the respondents that their identities will be disclosed only if they explicitly agree to be identified, to which all the respondents were reluctant considering the sensitivity of the subject matter.

Table 4. *Details of the professors interviewed*

Professors	University	Designation	Interview date (dd/mm/yyyy)
Professor 01 (P01)	A noteworthy agricultural and technology university accredited A++ by NAAC	Assistant Professor	21-09-2025
Professor 02 (P02)	One of the oldest technology universities having a 105- year history and accredited A+ by NAAC	Assistant Professor	24-09-2025
Professor 03 (P03)	A reputed law university established in 2005 and accredited A by NAAC	Professor	27-09-2025
Professor 04 (P04)	A 115-year medical university accredited A++ by NAAC with a CGPA of 3.67	Assistant Professor	30-09-2025
Professor 05 (P05)	A language university situated in the capital city of a key Indian state and accredited B++ by NAAC	Assistant Professor	02-10-2025
Professor 06 (P06)	One of the prominent open universities having more than 80,000 learners enrolled	Associate Professor	05-10-2025
Professor 07 (P07)	A university dedicated to the study of Sanskrit language and accredited A by NAAC	Assistant Professor	06-10-2025
Professor 08 (P08)	A leading technology university ranked in top 100 for engineering and accredited A by NAAC	Assistant Professor	11-10-2025
Professor 09 (P09)	A university established for the welfare of persons with disabilities and accredited A by NAAC	Professor	17-10-2025
Professor 10 (P10)	One of the largest universities of India with more than 4,00,000 enrolments and accredited A by NAAC	Associate Professor	22-10-2025
Professor 11 (P11)	A 100-year-old university established for the promotion of music and accredited A++ by NAAC	Assistant Professor	26-10-2025
Professor 12 (P12)	A leading university with more than 550 affiliated colleges and accredited A++ by NAAC	Assistant Professor	01-11-2025
Professor 13 (P13)	One of the top 5 universities in India as per NIRF rankings and granted with institute of eminence status	Assistant Professor	08-11-2025

Professors	University	Designation	Interview date (dd/mm/yyyy)
Professor 14 (P14)	A 150-year-old central university accredited A+ by NAAC with a CGPA of 3.26	Assistant Professor	11-11-2025
Professor 15 (P15)	A recently established and rapidly growing central university accredited A++ by NAAC	Associate Professor	14-11-2025
Professor 16 (P16)	A university running many professional and vocational study programmes accredited A++ by NAAC	Associate Professor	19-11-2025
Professor 17 (P17)	An almost 70-year-old state government university recently accredited by A++ by NAAC	Professor	24-11-2025
Professor 18 (P18)	A more than 100-year-old state university with a large alumni base accredited B++ by NAAC	Assistant Professor	24-11-2025
Professor 19 (P19)	One of the reputed state government universities of India recently accredited A++ by NAAC with a CGPA of 3.55	Assistant Professor	24-11-2025
Professor 20 (P20)	A relatively new state government university growing quickly with more than 250 affiliated colleges	Associate Professor	29-11-2025
Professor 21 (P21)	A university dedicated to the study of Sanskrit language and accredited A by NAAC	Associate Professor	04-12-2025
Professor 22 (P22)	One of the oldest technology universities having a 105- year history and accredited A+ by NAAC	Assistant Professor	08-12-2025
Professor 23 (P23)	A university established for the welfare of persons with disabilities and accredited A by NAAC	Assistant Professor	13-12-2025
Professor 24 (P24)	One of the top 5 universities in India as per NIRF rankings and granted with institute of eminence status	Associate Professor	17-12-2025
Professor 25 (P25)	A relatively new state government university growing quickly with more than 250 affiliated colleges	Professor	20-12-2025
Professor 26 (P26)	A university established for the welfare of persons with disabilities and accredited A by NAAC	Assistant Professor	24-12-2025
Professor 27 (P27)	A leading technology university ranked in top 100 for engineering and accredited A by NAAC	Assistant Professor	30-12-2025
Professor 28 (P28)	A leading university with more than 550 affiliated colleges and accredited A++ by NAAC	Associate Professor	31-12-2025
Professor 29 (P29)	A noteworthy agricultural and technology university accredited A++ by NAAC	Assistant Professor	07-01-2026
Professor 30 (P30)	One of the reputed state government universities of India recently accredited A++ by NAAC with a CGPA of 3.55	Professor	14-01-2026
Professor 31 (P31)	A 150-year-old central university accredited A+ by NAAC with a CGPA of 3.26	Associate Professor	19-01-2026
Professor 32 (P32)	One of the prominent open universities having more than 80,000 learners enrolled	Assistant Professor	23-01-2026
Professor 33 (P33)	A leading technology university ranked in top 100 for engineering and accredited A by NAAC	Assistant Professor	28-01-2026
Professor 34 (P34)	A more than 100-year-old state university with a large alumni base accredited B++ by NAAC	Associate Professor	31-01-2026
Professor 35 (P35)	A relatively new state government university growing quickly with more than 250 affiliated colleges	Assistant Professor	03-02-2026
Professor 36 (P36)	A 115-year medical university accredited A++ by NAAC with a CGPA of 3.67	Associate Professor	05-02-2026
Professor 37 (P37)	An almost 70-year-old state government university recently accredited by A++ by NAAC	Assistant Professor	12-02-2026
Professor 38 (P38)	A more than 100-year-old state university with a large alumni base accredited B++ by NAAC	Professor	15-02-2026
Professor 39 (P39)	A language university situated in the capital city of a key state and accredited B++ by NAAC	Associate Professor	22-02-2026
Professor 40 (P40)	One of the top 5 universities in India as per NIRF rankings and granted with institute of eminence status	Professor	28-02-2026

Figure 1 presents the time span of each professor interview and the majority of interviews fell within the duration range of 23 minutes to 34 minutes. The mean length of the interview was 29.22 minutes

where the shortest interview took place with associate professor 31 which lasted for 19 minutes. The interview with assistant professor 5 was the lengthiest, spanning a total of 42 minutes.

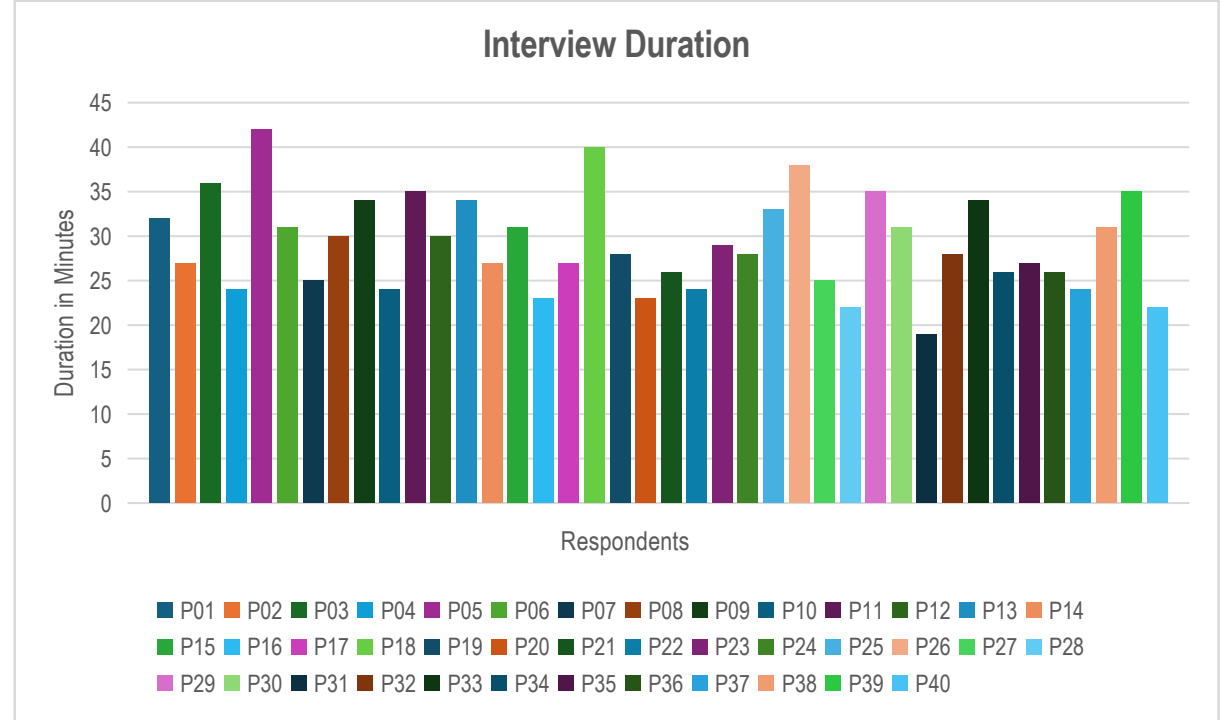


Figure 1: Time consumed in interviewing professors

In accordance with the operational definition elucidated above, the study emphasized on the identification of failures encountered in cognitive processing particularly related to information overload. Each theme in the list below is related to one or more of the four interpretive benchmarks (functional memory saturation, task switching cost, personal cognitive stress, or information processing deficit). The under mentioned seven themes surfaced constantly throughout all interviews. The core themes that transpired through the careful scrutiny of transcripts collected by the researcher were task switching and interruptions, pedagogical impact, cognitive symptoms, social manifestations, behavioural manifestations, physical and emotional toll, coping and support.

Task switching and interruptions

The fundamental notion of “non-academic work” is now out of the equation, every single thing that the university administration expects us to do has to be at the very top of our priority list. If, while we are engaged in teaching a key concept in the class and we are at once asked to prepare for an urgent accreditation meeting, the psychological association breaks entirely. Thereafter, simply regaining that level of focus takes at least two days. This has happened so many times now that we have submitted to the belief that “multitasking” is our basic motto—although the quality of the delivery is compromised (P01, P04). So, the frequent switching between teaching and administrative tasks is detrimental to quality. The repeated loss of focus makes effective classroom performance lacklustre, leading to imminent dejection among professors (McInnis, 2000). On similar grounds, continuous disruptions diminish the quality of research, and academic writing also suffers drastically. I view regular task switching and continuous interruption as a hurdle. Yes, repeated obstructions are definitely an issue—mainly when you are involved in extensive research or original writing. The trouble emerges when some tasks are abruptly forced upon you. Although I strive to set clear boundaries but regaining the lost focus is difficult (P02, P11, P16).

This constitutes a form of organized cruelty being imposed on our intellectual being. If the administrative machinery feels that teachers are machines, then they should be reminded that even the most well-oiled machines need time to reboot (P10). The ever-increasing cognitive burden in universities is gravely testing the mental limits of professors. Today’s workload is excessive, and while keeping pace with time is essential, it is equally important that university administration respects human capabilities (Berg and Seeber, 2025). After three decades of active service, I can state this with utmost sincerity and certainty

that while working in a university you are bound to manage a multitude of tasks concurrently. Through my observations I can state that when I first came into service some 32 years ago, the sheer volume of tasks was far less than it is today. Still, the right way to move forward is to reconcile with the modern times; or else, stress is bound to occur (P30).

This question aligns with the thought process of every teacher who had set his foot in academics to teach and perform quality research, yet today finds himself narrowed down to the status of an office worker. The single most worrisome mess affecting our universities is mental fatigue. The sad part is that by the time we somehow manage to reclaim our focus, the day is almost over (P05, P13). In such an alarming situation where, mental fatigue is diverting state-run university professors from teaching and research, the core competencies are clearly getting eroded (Foli et al., 2025). It is indeed a matter of grave concern which needs to be dealt with immediately. I would take this liberty and say that we, as teachers, are slowly giving up on our core competence since we have turned ourselves into 'managers,' rather than 'educators', whatever may be the reason (P07).

Pedagogical impact

Very recently, the deadline for submitting the Annual Performance Assessment Report (APAR) was approaching at my university. I was engaging a class for the M.Sc. students. I was standing there, writing quantum mechanics equations on the board—but my mind was roaming in the midst of the APAR modules which were yet to be finalized. At one point, a student came up with a query, which I answered; nonetheless, I later figured out that I didn't even entirely listen to the question (P06). The preoccupation of mind with administrative tasks is impairing uninterrupted academic dialogue between the teacher and the taught (Mintrop and Charles, 2017). The circumstances have become so intense that professors are getting forced to present study material mechanically. Once, while I was delivering a lecture on the Union Territories under the Indian Constitution, my mind was engrossed with a University Purchase Committee meeting prior to which I had to sign the semester mark sheets also. Even though I kept going with my verbal flow, I had this feeling that I was not fully involved in a 'discourse' with the students, rather I was merely lecturing them (P15).

Honestly, sometimes it feels like a 'spiritual failure.' One day, I was teaching the poetry of John Milton, However, my focus remained with the committee convened in the Registrar's office, where the Pre-Ph.D. coursework matter awaited resolution. Though, I recited the poetry, I failed to become absorbed in its true meaning. Although, I have resolved that, from now on, I observe at least ten minutes of silence before entering the classroom (P05). The persistent inability of state-run university professors to immerse themselves in teaching due to cognitive overload is making them feel that there is a serious lack of full presence on their part. Yet, there is a belief that in times of lack of energy there is no harm in taking honest breaks (Headlee, 2020). I would call this issue a 'multitasking failure.' Whenever I notice that the students are getting bored because of lack of energy in me, I pause the lecture midway with the intention to hold extra classes on the next working day. I believe it is far better to honestly take a break in such situations. The students appreciate this as well (P08, P21). Moreover, expanding administrative pressure in universities is eroding academic discipline, making this disconnect a strange routine. Nevertheless, the administrative pressures in universities have become so immense that academics has been confined to a secondary role. No innovation involved, no voluntary dialogue. It is an upsetting state of affairs, but this is the 'new normal.' (P10, P29, P37)

Cognitive symptoms

This question strikes a deep chord with me because the incidents like these have now become very common. The brain simultaneously swirls with thoughts of administrative files, a Ph.D. scholar's thesis, and my electricity bill. My mind continues to be a storehouse of knowledge, still the key to approach it has probably gotten buried somewhere underneath a soaring stack of non-academic work (P21). There is a mental tangle encountered in the midst of university-level tasks known as 'cognitive overload.' Further, while negotiating committee coordination, admissions and examination related work in the university, professors tend to lose sight of their core purpose. This shows that this is not merely a usual occurrence, but rather a sign of deeper concern. I would term this a 'cognitive overload.' And yes, this has been occurring with me frequently. Not long ago, I was made the convener of a committee within my faculty, and concurrently, admission work

was in progress. I came to my office, unlocked the door, went in, and then sat there thinking about the exact purpose I had come for? I don't believe that this is a normal phenomenon, rather a warning sign (P36).

Yes, this happens to me. When you are simultaneously serving as the chairperson of three university-level committees, supervising five research scholars, and confronting the pressure of collecting data for rankings like NAAC and NIRF, the mind gets confined in a 'multitasking trap.' It depicts the critical point where the mind fundamentally refuses to take any further load (P27). While the "multitasking trap" represents the brain's limit, the "professorial blank moments" refer to an intense form of mental fatigue (Vveinhardt and Sroka, 2022). The mind becomes absolutely drained due to mounting workload, which underscores the mental state of professors. They have come to a point, where the brain disapproves of any further supplementary load. I've even coined a name for situations like these—'Professorial Blank Moments.' What happens with me is that sometimes, I just stare at my notes, striving to find out the exact topic which was covered in the previous session. It becomes extremely draining (P14, P18).

Social symptoms

At the beginning of my career, I used to say 'yes' to every research collaboration and every new research opportunity. Yet, over a period of time, I have hopelessly declined many opportunities for international association. I feel "mentally overcharged" just because I do not have sufficient time for research (P18, P26, P39). Cognitive overload induced time constraint is now forcing even those professors who are in the early stages of their career to turn down international collaborative opportunities as they are left with no choice (Koudsia and Kirchner, 2024). This mental burden reaches its peak when administrative responsibilities, such as headship of the department, compel them to refuse even gripping research collaborations. I was recently about to commence on a research paper in sustainable marketing alongside a young researcher. The theme was completely new and stimulating to me. But once I went through my schedule, I figured out that the administrative responsibility of being the Head of the Department, attending perpetual administrative meetings and on top of that, the reporting requirements forced me to give up on the exciting collaboration. I had to eventually decline (P16). Cognitive overload has risen as a threat because it has completely inundated the capacity of professors by making the new partnership seem certain to fail. I would go to the extent to say that I have reached the point of overflow. I presently have four Ph.D. scholars, two ongoing research projects, and in addition to this, I serve as the Secretary of the department's Research Committee. Considering this, I have a strong feeling that if I take on any new research collaboration, either the project will fail, or I will (P11).

Behavioural manifestations

"In recent times, perhaps, I have noticed, a distinct note of irritability in my voice. Patience is a quality for which I am widely known. My students always said, "Ma'am, do you ever get angry?" Yet, in recent months, I have started to witness changes in me. On one occasion, I was concurrently drafting minutes of the meeting for two different committees when an M.Sc. student came up to me. She asked a simple question which was regarding the Fredholm integral equation formula. I looked at her in irritation and replied "That is elementary knowledge, you should have memorized it by now?" This incident serves as a stark reminder that the cognitive overload we bear is slowly robbing us of our gentleness (P22). Cognitive workload has caused a severe decline in the patience level of Indian professors. It has not only inflated the irritability factor but is also affecting the relationship structures (Das, 2025). Moreover, cognitive overload is impairing the composure. Yes, it happens. And I feel no hesitation in admitting it. However, I would also like to add that I am not solely responsible for this. When you are subjected to so many pressures simultaneously, your patience begins to wear thin. Sometimes, we do get this realization that our exasperation is not directed at our colleagues or students, but rather at the establishment that is overtiring us and just because of this our relationships are the first thing to suffer (P17, P25, P37). It is important for professors to acknowledge that losing patience under extreme pressure is natural, which can impact relationships. But what matters is the resolve to prioritize personal relationships and remain patient. Over the past few months, I have found myself growing irritable even towards my peers, family and some close acquaintances. Perhaps a hint of impatience in my tone has crept in. Honestly, I have started to feel that people are shying away from me. But now, I have made a firm resolve that no matter how big the workload, I would never lose patience with people I really care for (P14).

Physical and emotional toll

I have noticed myself minutely that on days when I have to spend seven or eight consecutive hours attending back-to-back physical and virtual meetings or evaluating end semester examination answer books, by evening, my eyes start to feel burning sensations, and I experience head pressure. This is not ordinary fatigue; rather, it is the integrated effect of 'digital eye strain' and 'mental fatigue.' The sad part is that I cannot afford avoidance as the deadlines are stiff and the system commands that results must be delivered quickly (P05). The two fundamental reasons behind the problems faced by professors are persistent workload and emotional fatigue. They suffer from "health-related issues" like digital eye strain and neck and shoulder stiffness (Wood, 2020). Still, they feel compelled to disregard their health in the face of challenging times. *Being the senior most professor and the chief proctor in my university, I have to juggle committee meetings, resolve disciplinary matters and above all evaluate the answer sheets. These days, I have begun to invariably experience stiffness in my neck and shoulders by late afternoon, followed by a blurring of vision. The worst part is that these health issues don't usually get cured with ordinary medication because they are not a result physical exertion only, but of mental fatigue as well (P25).* Therefore, a rational assessment is that prolonged sitting and mental stress are causing physical problems such as stiffness in the neck and shoulders and blurred vision (Jasnak and Rao, 2025). Furthermore, the inability to take rest at regular intervals is making these issues even worse.

Last semester, when I spent around 45 consecutive days preparing the self-study report of my university to be submitted on the NAAC portal, the pain in my neck became so grievous that I just could not move my head. Seeking medical attention, I had to approach a physiotherapist who told me that my posture has deteriorated due to prolonged sitting and I have become a possible candidate of spondylitis. But still when deadlines emerge and there is pressure to submit data, how can I hardly just get up and go for a walk? Although, I am now planning to make it a rule to take a ten-minute break every hour (P20). The extent of despair among professors is such that despite doctor's warnings, they do not envision a possibility of change in their lifestyle unless changes are instituted in university functioning. *The doctors are now literally reprimanding us to either change our lifestyle or invite stress-induced hypertension. Nonetheless, we are helpless, because unless changes are installed in the way the university functions a lifestyle change seems like a joke and the pain behind it runs deep (P18, P23, P31, P35, P40).*

Coping and support

At our university, there is no formal support system in place where we can offload the sheer volume of work we are burdened with. Informally, I "redistribute" it to my research scholars. All the rudimentary administrative tasks like filing and document compilation are handled entirely by our research students. We know this isn't just, but we are short on choices (P23, P34, P38). In the light of growing cognitive burden on professors, they are forced either to shift a sizeable portion of the workload onto the students or to make temporary arrangements at their own level (Manuel et al., 2018). On top of this, there is a serious lack of robust policies and systems at university level. *The one who is once bestowed upon the responsibility of a task by the administration does it till eternity. There is no mental health support at the university, nor is there any precise policy for the allocation of workload. However, informally, I have created a small "support system" of my own. Yet, these are all only makeshift measures. The real respite must come at the institutional level (P05).*

Frankly speaking, I don't see any staff help desk or a workload assessment committee in the university, and even if there is one, it is probably functional only on paper. So, to offload my work, I have conceived a mechanism-I have learned to "prioritize my procrastination." The most compelling tasks are completed first and the rest keeps getting rescheduled (P29). In the absence of university-level formal support, professors resort to prioritizing through procrastination for cognitive load management. They do not shy away from recognizing that psychological counselling for them is limited merely to paperwork, and the true support comes informally. *The formal support system is merely nominal. Our university has a 'Psychological Counselling Cell,' but its activities have been confined to nothing more than organizing guest lectures. The actual support is informal—our colleagues. At the institutional level, we are all fundamentally unattended (P20, P25).* Eventually, state-run university professors from India admit that formal support system is minimal, with the universities failing to provide psychological support (Kundu and Bej, 2025). *In our universities, 'mental support' seems to be missing. As a personal coping mechanism, we go out into our gardens and water the plants, in the evenings-This is our 'therapy.' (P16, P28, P32)*

Conclusion

The findings of the qualitative investigation lay out interesting factors that address the three research questions developed earlier about the different possible effects, manifestations and strategies to mitigate cognitive overload. This paper set out to investigate the current status of cognitive overload and its critical role in affecting the performance of state-run university professors in India. Findings clearly suggest that professors working in the state-run university framework in India endure immoderate cognitive overload. The primary contribution is to examine the challenges faced by the professors in efficiently managing their job-related responsibilities in the context of rising cognitive load coming from the administrative modus operandi of each university. The secondary contribution is to reveal the impact of cognitive overload on the effectiveness of academic and research performance of Indian professors.

Practical implications

This research carries diverse implications for university administrative staff and students. Professors at state-run universities in India confront a fundamental choice: whether to prioritize academic work over administrative tasks or the reverse. Ideally, professors should work more on the academic endeavours-such as instructional delivery, curriculum development, research mentorship and educational innovation-while treating administrative responsibilities as peripheral. The most prominent, though challenging, would be that professors treat their administrative role and their academic role as two distinct jobs that happen to be done by the same person. They need to build a strict psychological and behavioural firewall between the two (Mady, 2019). This research adds extensively to the existing knowledge of cognitive overload, academic exhaustion and coping and support of Indian professors because, till date studies in Indian scenario are scarce. The results of this research have direct and practical inferences for university executives, policy makers, and academicians. The recommendations that follow arise directly from the seven themes that have emerged from the study and are presented within a multi-layered university level framework as opposed to generic suggestions:

A. Recommendations derived from Findings:

1. Task switching and interruptions:
 - Assign certain days in a week as “academic priority days” where professors are free of administrative gatherings and low-priority correspondence.
 - Provide at least two to three hours per day on a continuous basis for teaching readiness, research and student assistance cum mentoring.
 - Confinement of administrative meetings to only two particular days in a week.
2. Pedagogical impact:
 - Enforce a compulsory and quick 10-minute “de-pressurization” session before each class in which faculty revisit their teaching goals bereft of any administrative interruptions.
 - Establish a rigorous “no interruptions” policy during teaching time, deferring all administrative correspondence until the class is done.
 - Provide a way for professors to label “teaching preference” status on their schedules, to signify that they are not available for administrative assignments.
3. Cognitive symptoms:
 - Create a simplified quarterly self-appraisal mechanism for professors with administrative portfolios according to the four criteria employed in this research (functional memory saturation, task switching cost, personal cognitive stress, or information processing deficit).
 - Develop a “cognitive load index” that aggregates academic load, number of administrative portfolios, membership of committees, and accreditation responsibilities; establish a maximum admissible threshold score.
 - The university administration needs to ensure that no one professor can hold more than two major administrative positions at a time.

4. Social symptoms:

- Provide a “research sabbatical leave” every three years wherein administrative responsibilities are decreased to the extent of 50% to make room for research collaborations.
- Create an earmarked university fund to recruit research assistants on part time basis to undertake administrative documentation for funding proposals and collaborative projects.
- Develop a mentoring scheme for junior professors to partake administrative loads with experienced colleagues during high-demand intervals of research activity.

5. Behavioural manifestations:

- Offer compulsory training sessions on emotional intelligence, endurance and self-assured correspondence for professors who have administrative roles.
- Arrange monthly “debriefing sessions” among professors to share tough interpersonal experiences and comprehend coping schemes.
- Make sure that classified advisory services are available and diligently advertised to professors who encounter testiness or relationship stress.

6. Physical and emotional toll:

- Implement mandatory 10-to-15-minute motion breaks after every 90 minutes of rigorous administrative or grading task.
- Ergonomic assessments and adaptable workspaces for professors with elevated administrative burdens.
- Offer health and wellness interventions like sponsored physiotherapy, subsidized eye care and psychological health consultancy.
- Limit sustained screen-based tasks to a capping at six hours a day.

7. Coping and support:

- Form an institutionalised Workload Assessment and Support Committee at the university level to evaluate and fairly spread administrative duties among all faculty members.
- Establish a dedicated Staff Help Desk to assist faculty with critical administrative support (filing and documentation) during high intensity periods.
- Build a peer assistance circle so professors can briefly unload low priority tasks to coworkers during contingencies.
- Validate the role of Ph.D. scholars in helping with administrative tasks, if the ethical protocols are adhered to and their personal academic endeavour is not hampered.

B. Comprehensive university level framework for cognitive overload minimization:

The recommendations proposed in this study can be skilfully integrated through a three-layered pathway:

Table 5. *Proposed framework for cognitive overload reduction*

Tier	Level	Interventions	Accountable Party
1	Individual (Professor centered)	Cognitive load self-appraisal, block scheduling training, conscientiousness workshops, subsidized health camps	Professional / Human Resource Development Cell of the university
2	Faculty / Department (Operational unit)	Task preference mechanism, peer task offloading system, combined administration calendars, workload allocation cell / committee	Dean of the Faculty / Head of the Department / Faculty committees
3	Institution (Structural)	Administrative duty restrictions, policy for academic time priority, dedicated psychological cell assistance, persistent audits of cognitive load, definitive workload distribution policy	University Senate or Executive Council/ Office of the Vice Chancellor / NAAC or NIRF Coordination Committees

C. Model implementation framework:

- **Phase 1 (0-6 months):** Collect threshold cognitive load data, initiate mindfulness campaigns and set up faculty workload assessment committees.
- **Phase 2 (6-9 months):** Execute secured time policies, establish professors help desk and initiate workload reallocation.
- **Phase 3 (9-12 months):** Assess effectiveness with qualitative response cum assessment and quantitative cognitive load analysis; adapt interventions according to results.

Research limitations

Due to its qualitative nature, this study is limited by the inability to generalize the results. The purpose of qualitative research is to focus on concept development rather than universal applicability (Draper, 2004). Therefore, future studies should accentuate quantitative methodologies. Specifically, the factors identified in the results and discussion could be operationalized into a questionnaire, allowing a large-scale study to assess the influence of the themes identified in the interviews with professors. Furthermore, the relationships between the factors identified, namely task switching and interruptions, pedagogical impact, cognitive symptoms, social manifestations, behavioural manifestations, physical and emotional toll, coping and support would provide another encouraging opportunity for further research. Another alluring pathway for fresh research could be a study of the differences in perception of professors from state-run universities and private universities towards cognitive overload.

Conflict of interests

The author declares that he has no financial or personal associations that may have inappropriately directed him in writing this research paper.

Author Contribution

Shivam Shukla: conceptualization, data curation, formal analysis, investigation, methodology, project administration, supervision, validation, visualization, writing-original draft, writing-review & editing.

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Data Availability Statement

The datasets generated and analysed during the current study consist of semi-structured interview transcripts. These data are not publicly available due to confidentiality agreements with participants and the sensitive academic information contained within them. Illustrative, de-identified excerpts relevant to the study's findings are provided within this research paper.

Institutional Review Board Statement

The views and opinions expressed in this research paper are those of the author and are the product of professional research. They do not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher. The author is responsible for this research paper's results, findings and content.

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The Relationships among Knowledge, Beliefs, and Instructional Practices of Pre-Service and In-Service Mathematics Teachers: A Systematic Review

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Abstract: Various factors, including knowledge, beliefs, and instructional practices, influence the quality of pre-service and in-service mathematics teachers' instruction. The relationships among these factors have been investigated in many previous studies. This systematic review investigated the relationships among knowledge, beliefs, and instructional practices of pre-service and in-service mathematics teachers by analyzing included studies from 2015 to 2023. The study used systematic review methodology and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, along with descriptive and qualitative statistical analyses. A collection of 38 relevant studies, selected from databases such as Google Scholar, Mendeley, ScienceDirect, Scopus, and Taylor & Francis Online, was analyzed to answer the research questions after a screening and eligibility assessment using inclusion and exclusion criteria. The research results on the relationships among knowledge, beliefs, and instructional practices of pre-service and in-service mathematics teachers reported in the included studies are relatively diverse. In particular, most research shows that teachers' knowledge affects their beliefs and the quality of teaching in their instructional practices. In contrast, their instructional practices promote the development of their knowledge, reflect, and enhance their beliefs. However, the proportion of studies finding the relationships among these factors to be insignificant remains relatively low. Based on these findings, the study makes recommendations to stakeholders for in-service mathematics teachers' professional development and training, as well as pre-service mathematics teacher training programs. In addition, the study highlights limitations and suggests new research directions for the future.

Keywords: Beliefs, instructional practices, knowledge, mathematics teachers.

Introduction

Teachers' knowledge, beliefs, and instructional practices are three areas of research interest and are also essential to the effectiveness of the teaching process. The relationships among the above three factors are also of interest to many researchers in studies related to professional development for teachers (pre-service and in-service). Many empirical studies have shown that the quality of teachers' instruction is one of the main factors affecting student learning outcomes (Hattie, 2009, as cited in [Baier et al., 2019](#); [Hasim et al., 2022](#); [Pagiling and Taufik, 2022](#)). Therefore, teachers need professional development to improve their knowledge, understanding, and instructional practices to ensure student learning development ([Hasim et al., 2022](#)). As a result, educators frequently conduct research on methods to improve teacher education and to predict teaching quality based on teachers' knowledge and beliefs ([Baier et al., 2019](#)). In particular, teachers' professional knowledge, including conceptual and practical knowledge of general pedagogy and subject content, is core to their overall competency ([Hasim et al., 2022](#)). According to these authors, teachers with solid, extensive knowledge can apply various teaching strategies, primar-

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ily to support students in becoming self-aware and strategic learners (Hasim et al., 2022).

Research on the influence of teachers' beliefs on instructional practices is considered an important aspect of mathematics education. In particular, mathematics teachers' beliefs include two main aspects: beliefs about the nature of mathematics and beliefs about teaching and learning mathematics (Balanlay, 2021). According to Nguyen and Tran's (2023) study, mathematics teachers held sophisticated beliefs about teaching and learning, a holistic view of knowledge, and mathematical proficiency. Therefore, many previous studies suggest that belief and knowledge are two factors that affect teachers' instructional practices in the classroom (Muhtarom et al., 2019; Purnomo et al., 2016). At the same time, many studies continue to show a relatively weak relationship among mathematics teachers' knowledge, beliefs, and instructional practices (Auslander et al., 2023; Moh'd et al., 2021). Therefore, it can be observed that previous studies have yielded both consistent and inconsistent conclusions regarding the relationships among the elements of knowledge, beliefs, and instructional practices of mathematics teachers (Kaspersen et al., 2017).

Several systematic reviews have previously examined the relationships among knowledge elements, beliefs, and instructional practices of mathematics teachers. Depaepe et al. (2020) surveyed studies on the relationship between teachers' professional knowledge and the quality of their instructional practices in mathematics education. First, the study provided an overview of approaches for defining mathematical expertise. Second, the relationship between teachers' professional knowledge and instructional practices was highlighted, with a focus on the indirect roles of teachers' professional beliefs and their situation-specific knowledge and skills. Third, the study described the teacher competency model as an integrated model of knowledge, beliefs, situation-specific skills, and classroom behavior. The study discussed current research on the relationship between teaching quality and professional teacher knowledge. Another study by Hasim et al. (2022) on STEM (Science – Technology – Engineering – Mathematics) education and sustainable development identified sustainable development activities in STEM education and their impact on teacher knowledge and teaching methods. Peer-reviewed studies published between 2017 and 2021 were selected from the Scopus, Web of Science, and EBSCOhost databases. Research shows that sustainability activities in STEM had an indirect but strong influence on teachers' knowledge and instructional practices. In particular, Minarni et al. (2018) conducted a narrative review to discuss the relationships between teachers' teaching beliefs and practices, their instructional practices and student learning outcomes, and their beliefs and instructional practices and learning outcomes. Research results indicate that (1) mathematics teachers' beliefs guide them in determining the instructional practices they consider appropriate, (2) student-centered learning approaches improve student learning outcomes, and (3) teachers' beliefs and instructional practices, along with a student-centered approach, can motivate students to build mathematical knowledge and improve math learning outcomes actively. The difference between the current study and the previous studies is that this study aims to compile information regarding various studies covering the relationships among knowledge and beliefs, beliefs and instructional practices, and knowledge and instructional practices among pre-service and in-service mathematics teachers by using a systematic review guided by the PRISMA in educational and social science journals published worldwide from 2015 to 2023. Additionally, this study discusses various research methodologies used in selected studies, enabling researchers in the field of mathematics education to determine appropriate approaches for their future studies.

The relationships among knowledge, beliefs, and instructional practices are a topic of considerable interest, and the research literature is divided on the degree to which these factors are correlated (Kaspersen et al., 2017). Previous studies have yielded few results on the influence of beliefs on mathematics teachers' instructional practices. Fennema et al. (1996; as cited in Lui and Bonner, 2016) did not find the expected relationship between beliefs and changes in mathematics instructional practices. As cited in Thompson (1992; as cited in Lui and Bonner, 2016), several qualitative studies have shown a relatively weak relationship between beliefs and instructional practices. The previous results of insignificant associations between beliefs and practices may be due to many external factors influencing teacher instructional practices, such as school and classroom habits and resources. Second, further research is needed on the significance of beliefs and knowledge in instructional planning. The study by Cady et al. (2006; as cited in Lui and Bonner, 2016) suggested that content knowledge, pedagogical knowledge, and professional experience may mediate the relationship between teachers' teaching beliefs and practices. This study aims to explore the complex, intertwined relationships among these factors, as previous studies have concluded. Thus, a systematic review is required to provide an overview of recent research

on the relationships among pre-service and in-service mathematics teachers' knowledge, beliefs, and instructional practices. The findings of this study can serve as a reference for designing mathematics teacher education and professional development programs. Additionally, by identifying research gaps, the paper opens the door to future studies that will delve deeper into specific aspects of these relationships.

Knowledge describes the cognitive aspects of teachers' competencies (Dunekacke et al., 2016). The concepts of teachers' knowledge encompass subject knowledge, curriculum, pedagogy, global issues, and other topics (Carney et al., 2016; Lo, 2023). Mathematics teachers' knowledge can be defined as a three-dimensional structure that includes mathematical content knowledge, mathematical pedagogical content knowledge, and general pedagogical knowledge (Abdul Rahman et al., 2019; Dunekacke et al., 2016; Tinh et al., 2021; Yang et al., 2020). In the "in-the-head-of-teacher" context, teachers' content and pedagogical content knowledge can be distributed and situated (Kaiser et al., 2017). Content knowledge is knowledge acquired from books during the learning process and includes mathematical definitions, concepts, algorithms, and procedural knowledge (Blömeke and Kaiser, 2014; Dong et al., 2020), belonging to different branches of mathematics such as algebra, geometry, numbers, and data (Blömeke and Delaney, 2012). Meanwhile, pedagogical content knowledge is subject-specific knowledge for teaching and helps students absorb knowledge (Shulman, 1986; as cited in Yang et al., 2020). Pedagogical content knowledge is often divided into two main components, including knowledge about how to teach concepts (how to present concepts and knowledge about problems) and knowledge about students' thinking (how to present concepts and knowledge about problems) and knowledge about students' thinking (students' perceptions and confusion) (Scheiner et al., 2019; Copur-Gencturk and Li, 2023; Yang et al., 2020), allowing teachers to predict students' options and confusions when solving problems, explain students' ideas, and predict students' responses to specific tasks (Carney et al., 2016). Many empirical studies have confirmed the importance of pedagogical content knowledge for the quality of teacher education and student learning outcomes (Copur-Gencturk and Li, 2023).

Beliefs are the foundation of thought and behavior, acting as "cognitive filters" through which new knowledge and experiences are interpreted and acted upon (Swan, 2006; as cited in Calleja, 2022; Lin, 2021). Therefore, belief helps predict individual behavior (Calleja, 2022; Dunekacke et al., 2016). In the context of education, teachers' beliefs are described as a combination of personal perspectives, deeply held values, judgments, and implicit assumptions about mathematics, curriculum, education, students, teaching, and learning, which were shaped by their knowledge, experience, and instructional practices (Calleja, 2022; Felbrich et al., 2012; Lamichhane, 2017).

Many studies have classified teachers' beliefs to explain better concepts in teaching mathematics, classroom roles, and teachers' choice of teaching activities (Calleja, 2022; Dunekacke et al., 2016). Askew et al. (1997) proposed three types of teachers' beliefs, called transmission, discovery, and connectionist, including beliefs about the nature of mathematics, beliefs about teaching mathematics, and how students learn mathematics (as cited in Calleja, 2022; Aljaberi and Gheith, 2018; Balanlay, 2021; Carney et al., 2016). In particular, beliefs about the nature of mathematics influence teachers' views on teaching and learning mathematics (Guler and Celik, 2023; Nguyen and Tran, 2023). Teachers' beliefs about the nature of mathematics concern cognition, concepts, meanings, rules, and mental images related to mathematics, while beliefs about teaching and learning mathematics are also important. Teachers' opinions on how mathematics is taught and how students learn mathematics were surveyed by Lamichhane (2017) and Yang et al. (2020). Specifically, a transmission belief views mathematics as a collection of fixed, specific, irrefutable knowledge based on deductive logic, to be transferred to students (Carney et al., 2016). A connectionist belief views mathematical content as a connected set of topics and concepts and focuses on students' problem-solving methods and strategies (Askew et al., 1997; as cited in Carney et al., 2016). With this in mind, teachers are expected to facilitate learning activities and discussions by providing challenges to clarify mathematical concepts and relationships (Carney et al., 2016). A discovery belief views mathematics as a unified synthesis of knowledge. This method involves the teacher acting as a facilitator, establishing a classroom setting where students can investigate ideas and approaches to problem-solving (Carney et al., 2016). In addition, teachers' beliefs can also be considered in terms of efficacy beliefs, that is, teachers' beliefs and awareness of their ability to teach students with different requirements and standards to achieve learning outcomes. Students are expected to participate and achieve outcomes (Ekstam et al., 2017). Research by Beswick (2012) shows that teachers with more than one belief type tend to teach consistently with a different belief type in each specific context.

Instructional practices occur in classroom settings, creating conditions for students to learn (Baier et al., 2019; Depaepe and König, 2018; Makamure and Jita, 2019; Wadanambi and Leung, 2019). Many researchers believe instructional practices can be considered from teacher-centered and student-centered approaches (Hogan et al., 2013). In particular, the student-centered approach has been adopted in many countries in recent years due to its ability to respond to educational reforms (Cai and Howson, 2013). Specifically, this teaching approach allows students to actively participate in activities to solve real-world, meaningful mathematical problems, creating conditions for them to predict, verify, collect information, analyze data, communicate, and collaborate (Yang et al., 2020).

Teachers' instructional practices can be described in terms of student learning support, classroom management, and cognitive activation (Baier et al., 2019). Learning support includes teachers' behaviors that create a friendly, personally supportive learning environment that motivates and encourages students to participate in learning and provide feedback (Baumert et al., 2010). Classroom management is considered adequate when teachers ensure continuous student learning and limit disruptions and conflicts in the classroom (Korpershoek et al., 2016). Additionally, teachers demonstrate instructional practices with high cognitive activation ability by providing students with cognitively challenging tasks and creating. Thus, instructional practices require both in-service and pre-service teachers to have knowledge, responsibility, attitudes, skills, and experience, thereby contributing to the development of teachers' knowledge in depth and breadth.

The relationships between knowledge and beliefs, knowledge and instructional practices, and teachers' beliefs and practices have all been the subject of numerous prior studies. The results of studies on the relationships between these factors are relatively diverse. Teachers' knowledge and beliefs have a close two-way relationship. Indeed, previous studies found that teachers with a strong background in mathematics hold strong beliefs about the nature of mathematics and mathematics teaching and learning, and vice versa (Abdul Rahman et al., 2018; Blömeke and Kaiser, 2014). In contrast, as the nature and teaching and learning of mathematics become more complex, teachers' content and pedagogical knowledge increase, with a greater demand for higher quality (Pagiling and Taufik, 2022).

Regarding the relationship between teachers' knowledge and instructional practices, many studies have shown the importance of knowledge for teacher teaching quality, contributing to shaping their instructional practices, especially for aspects of classroom management and student support (Baier et al., 2019; Carney et al., 2016; Dong et al., 2020; Ernest, 1989; as cited in Yang et al., 2020; Lui and Bonner, 2016). Specifically, mathematical content knowledge is directly related to teachers' instructional practices, whereas other types of knowledge, such as pedagogical content knowledge and general pedagogical knowledge, are closely related to them (Ernest, 1989; as cited in Yang et al., 2020).

The gap between theory and practice in education is a challenge educators must address to promote mathematics teaching and learning. Belief is considered one of the factors contributing to narrowing or widening that gap. Therefore, investigating the relationship between beliefs and mathematics instructional practices is necessary to provide an overview of the training and development of mathematics teachers (Purnomo et al., 2016). Regarding this relationship, many studies have confirmed that teachers' beliefs play a decisive role in their instructional practices and vice versa, for changes in their instructional practices can lead to a change in teachers' beliefs (Beswick, 2005; as cited in Calleja, 2022; Aljaberi and Gheith, 2018; Yang et al., 2023). According to Carney et al. (2016) and Dong et al. (2020), teachers' beliefs strongly influence how they apply new teaching methods and the depth and duration of their application. Specifically, teachers' beliefs, including beliefs about the nature of mathematics and beliefs about mathematics teaching and learning, play the role of contextual filters through which teachers categorize instructional practices (Aljaberi and Gheith, 2018; Lui and Bonner, 2016), interpret their experiences, shape their interactions with students, and conduct instructional activities in the classroom (Aljaberi and Gheith, 2018; Yang et al., 2023; Wadanambi and Leung, 2019). However, teachers' beliefs about efficacy are an important basis for predicting teaching quality, level of cognitive activation, and teacher learning support (Ekstam et al., 2017). In particular, teachers with high levels of efficacy beliefs often tend to teach student-centered, make efforts to apply new teaching methods, and support students' learning at an individual level (Holzberger et al., 2013; Saadati et al., 2019), as well as flexibility in classroom management and lesson design (Temiz and Topeu, 2013), while teachers with conventional beliefs tend to teach teacher-centered (Saadati et al., 2019). However, some studies still suggest no relationship between teachers' beliefs and instructional practices (Wilkins, 2008; as cited in Guler and Celik, 2023).

This systematic review investigates the relationships among three core constructs in mathemat-

ics education: knowledge, beliefs, and instructional practices among pre-service teachers and in-service teachers. The study synthesizes evidence from relevant studies published from 2015 to 2023. The following research questions defined the study's focus.

1. What are the essential characteristics of the included studies, such as year of publication, country, and research subjects (pre-service or in-service mathematics teachers)?
2. What research methods are used in the included studies?
3. What is the relationship between teachers' knowledge and beliefs?
4. What is the relationship between teachers' knowledge and instructional practices?
5. What is the relationship between teachers' beliefs and instructional practices?

Materials and methods

Design

To answer the above research questions, several different research methods can be used, such as the research of [Nguyen et al. \(2020\)](#), which uses bibliographic and content analysis methods; research by [Do and Phan et al. \(2021\)](#), [Phan et al. \(2022\)](#), and [Pham et al. \(2022\)](#) using the bibliometric analysis method. However, a systematic review effectively synthesizes and summarizes research results on a specific issue. It is a thorough, transparent process for identifying, evaluating, and synthesizing research evidence. It helps improve the accuracy of conclusions by considering consistency. It is summarized in the results of many studies on the same topic ([Juhl and Lund, 2018](#)), conducted methodically or scientifically, using a pre-designed protocol to collect and synthesize data with the lowest possible level of bias ([Hanley and Cutts, 2013](#)).

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines ([Moher et al., 2010](#)) to provide an overview of studies on the relationships among knowledge, beliefs, and instructional practices among pre-service and in-service mathematics teachers. The following diagram shows the study protocol (see Figure 1).

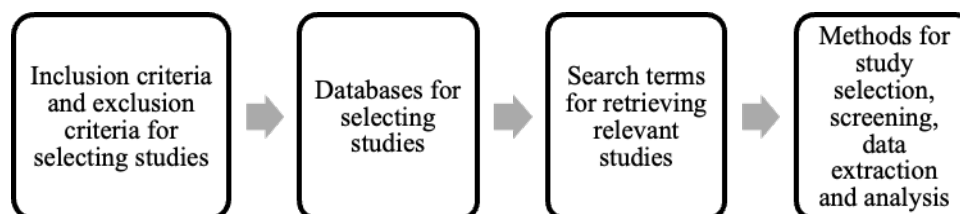


Figure 1. Protocol for selecting studies

Search methods

The databases were searched until the end of January 2024 to select studies that examined the relationships among knowledge, beliefs, and instructional practices of pre-service and in-service mathematics teachers. Various electronic databases were used, including Google Scholar, Mendeley, ScienceDirect, Scopus, and Taylor and Francis Online. These popular databases were available online and provided much relevant research on mathematics education. In particular, to limit the number of included studies and ensure the selection of high-quality studies, we selected studies by checking the Scopus database. Systematic review studies ([Andersen et al., 2022](#); [Hasim et al., 2022](#)) also had a similar database approach. In addition, to limit bias, the authors independently searched the above databases using predetermined search strings and criteria and performed title screening, abstract, and full texts based on those criteria to select for research. After working independently, the authors met to discuss the identified studies and agreed on the included studies.

The following search strings were used to find relevant studies on the research topic, with the syntax adapted for each database: (mathematics teachers) AND (knowledge), (mathematics teachers) AND (beliefs), (mathematics teachers) AND (instructional practices), (mathematics teachers) AND (practices), (mathematics teachers) AND (relationship) AND (knowledge), (beliefs), AND (practices). The search was limited to peer-reviewed studies published in English from 2015 to 2023.

Inclusion criteria

Selected studies were studies that met the following criteria: (1) experimental studies or survey studies, (2) research subjects that were pre-service or in-service mathematics teachers, and (3) examined the relationships among knowledge, beliefs, and instructional practices of mathematics teachers.

Exclusion criteria

Studies that were not selected fell into the following cases: (1) the research design was not experimental or survey, (2) the research object differed from pre-service and in-service mathematics teachers, (3) the research results were unrelated to the theme of the relationships among knowledge, beliefs, and instructional practices of mathematics teachers.

Search results

The database search yielded 163 relevant studies. The Excel platform established a database of authors, titles, year of publication, country, abstracts, research methods (sample, research design, instruments), and research results. After removing duplicate studies and selecting titles and abstracts, 65 studies were obtained. The full-text review and eligibility evaluation process was carried out following a discussion among members, during which 27 studies were excluded. After the study selection process, 38 suitable studies were chosen for analysis in this systematic review. Figure 2 shows the steps for selecting the included studies according to the PRISMA guidelines.

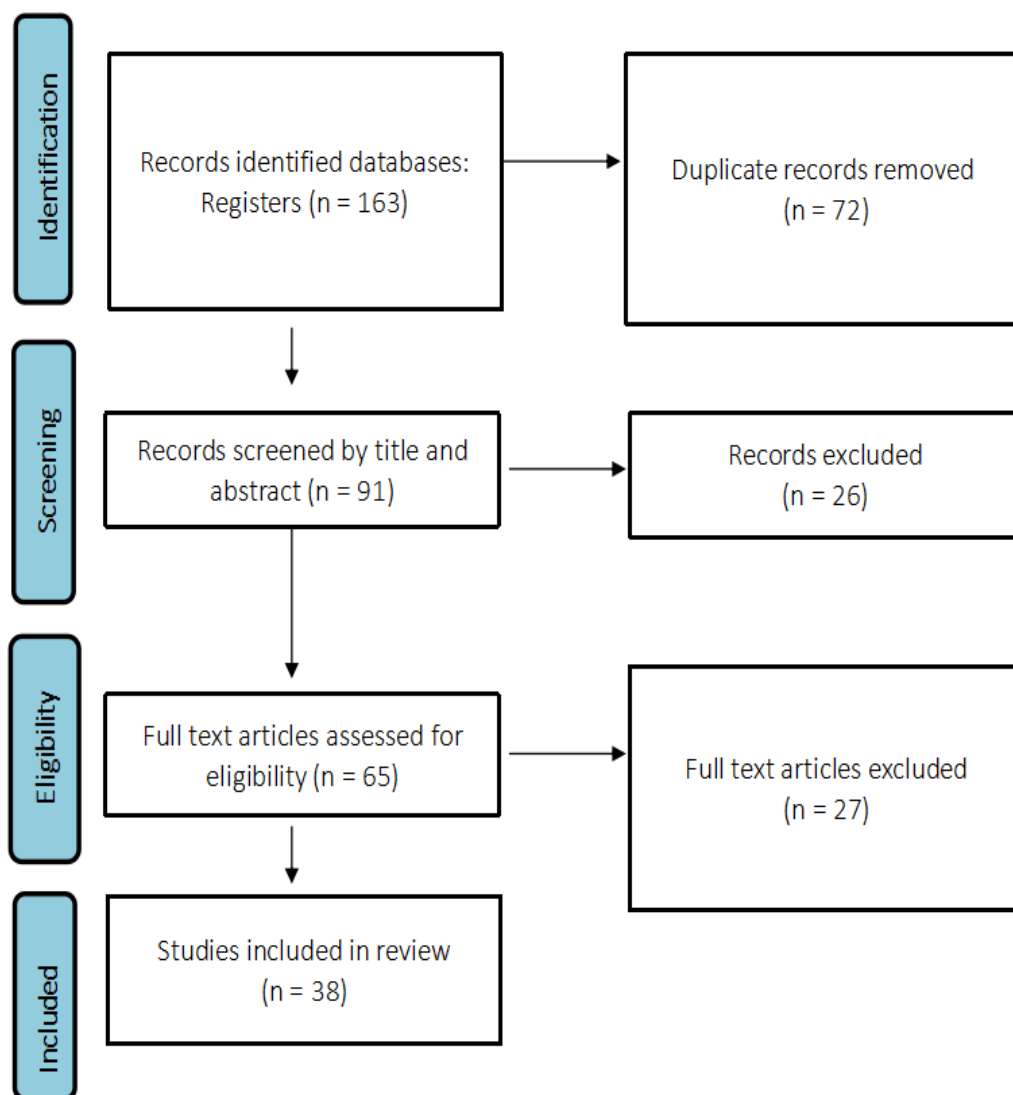


Figure 2. Selection process based on PRISMA (Moher et al., 2010)

Results

Research question 1: Demographic characteristics of the selected studies

The statistical results for the year of publication of the 38 selected studies are shown in Figure 3. It can be observed that, from 2015 to 2023, the number of studies published in 2022 and 2023 represents the highest proportion, with a rate of 21% (8 studies per year), whereas in 2019, 2020, and 2021 the rate was 11% (4 studies per year). Meanwhile, the number of studies published in 2015-2018 does not exceed 5 per year, representing no more than 10%.

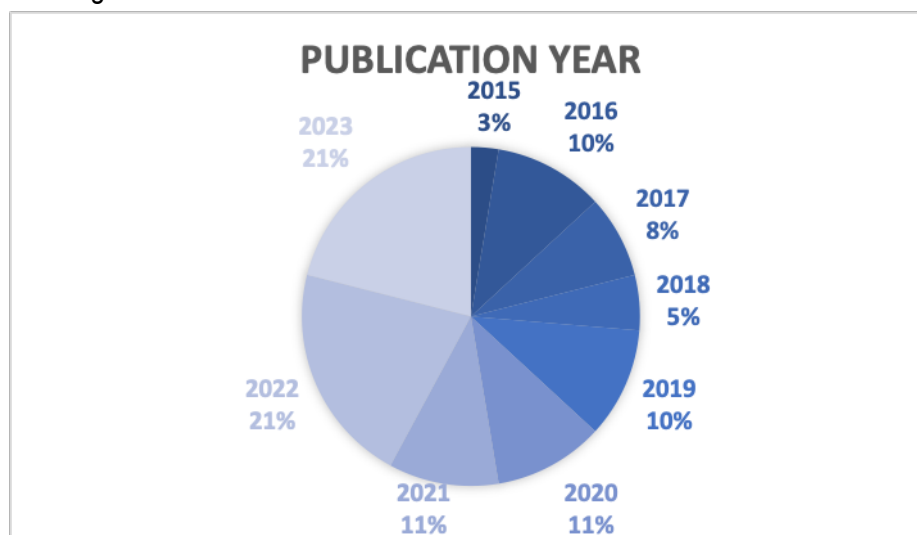


Figure 3. Distribution of the publication year

Geographical distribution statistics can be meaningful for practical comparisons of research results (Andersen et al., 2022; Ashraf et al., 2021). Figure 4 shows the distribution of country affiliations of the selected studies based on the information from the first author. Statistical results show that many studies on the relationships among knowledge, beliefs, and instructional practices of mathematics teachers have been conducted in the United States (11 studies) and China (7 studies). Meanwhile, the number of studies in other countries is significantly lower. In particular, four studies have been conducted in Germany, three in Indonesia, two in Turkey, and one in Brazil, Finland, Malta, Norway, the Republic of Korea, Rwanda, South Africa, Spain, Sri Lanka, Taiwan, Vietnam, South Africa, Sri Lanka, Taiwan, and Vietnam.

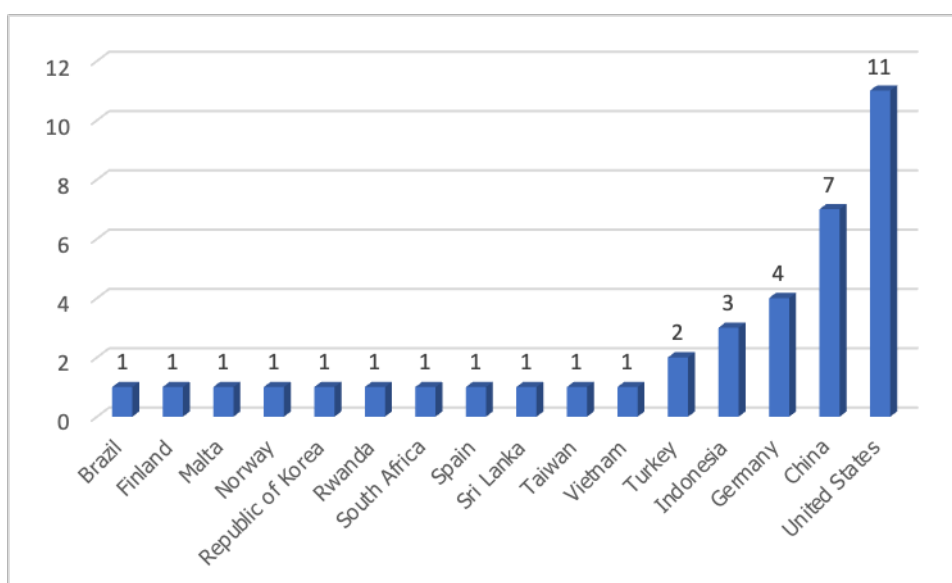


Figure 4. Geographical Distribution

The selected studies are experimental or survey studies that aim to clarify the relationships among the elements of knowledge, beliefs, and instructional practices of pre-service and in-service mathematics teachers. Therefore, the research subjects of these studies may include in-service teachers or/and/or pre-service teachers. The statistical results show that the research subjects in these studies are relatively diverse; however, most studies are conducted with in-service teachers. Specifically, 23 studies were conducted on in-service teachers, 13 on pre-service teachers, and two on research subjects, including both in-service and pre-service teachers; see Table 1.

Table 1. *Participants in the Included Studies*

Participants	Studies	n
In-service teachers	Auslander et al. (2023), Baron (2015), Calleja (2022), Carney et al. (2016), Copur-Gencturk and Li (2023), De Souza and Lopes (2021), Dong et al. (2020), Gomez Johnson and Williams (2023), Guler and Celik (2023), Hunt et al. (2023), Jenßen et al. (2022), Li et al. (2022), Moh'd et al. (2021), Moliner and Alegre (2022), Munter and Correnti (2017), Munter and Wilhelm (2021), Nguyen and Tran (2023), Suryanti et al. (2022), Thurm and Barzel (2020), Yang et al. (2021), Yang et al. (2023), Yu et al. (2022), Zhang (2022)	23
Pre-service teachers	Dunekacke et al. (2016), Ekstam et al. (2017), Guler and Celik (2018), Kaspersen et al. (2017), Kim (2018), Lin (2022), Lo (2023), Makamure and Jita (2019), Muhtarom et al. (2019), Purnomo et al. (2016), Rakes et al. (2022), Wadanambi and Leung (2019), Yang et al. (2020)	13
Both	Baier et al. (2019), Lui and Bonner (2016)	2

Research question 2: Research methods of the selected studies

The selected studies use various research designs to investigate the relationships among mathematics teachers' knowledge, beliefs, and instructional practices, including experimental, case study, and survey designs (see Figure 5). In addition to the advantages of experimental research with longitudinal data sets and survey research being possible with sufficiently large sample sizes, the use of case studies allows the review, observation, and analysis of relevant real-life conditions in researching the relationships among elements of teachers' knowledge, beliefs, and instructional practices (Calleja, 2022; Yang et al., 2023). The statistical results show that 14 of the 38 selected studies were experimental, 14 were surveys, and 12 were case studies.

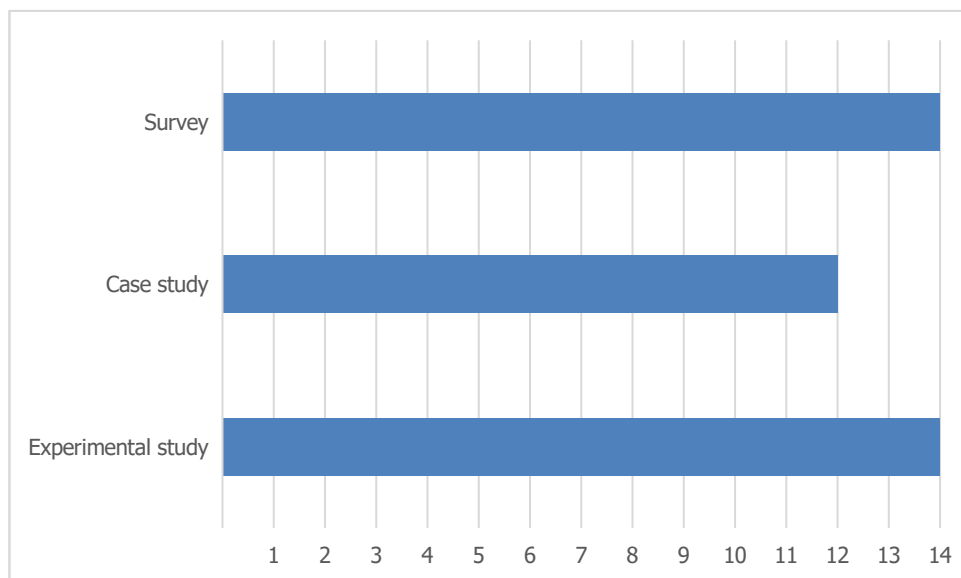


Figure 5. *Research designs of the included studies*

According to Figure 6, the selected studies employ a range of research methods, including quantitative, qualitative, and mixed-methods approaches. Consequently, 21% of the selected studies are qualitative, 36% are quantitative, and 43% are mixed methods studies.

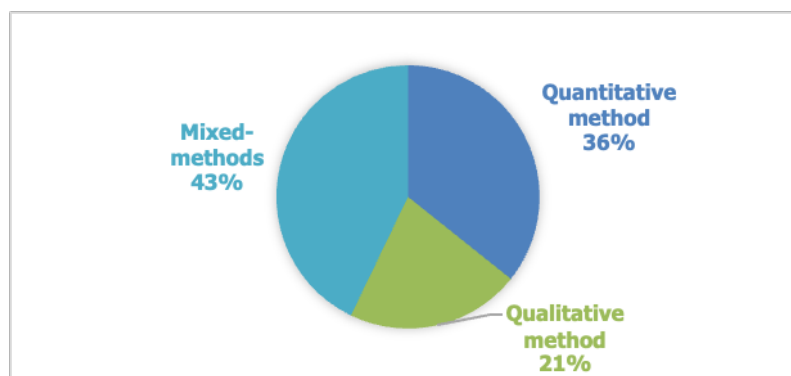


Figure 6. Research methods of the included studies.

The selected studies involve research subjects, including pre-service and in-service mathematics teachers, and sample sizes vary across studies depending on the research design. The statistical results show that 10 studies have sample sizes of less than 20, most of which are case studies. Meanwhile, the remaining 28 studies, 11 with sample sizes greater than 200, are surveyed and experimental. The study with the smallest sample size was conducted by [Purnomo et al. \(2016\)](#) with 1 participant, and the study with the largest sample size was carried out by [Carney et al. \(2016\)](#) with 3933 participants.

The selected studies use various assessment instruments to evaluate the relationships among pre-service and in-service mathematics teachers' knowledge, beliefs, and instructional practices, including tests, surveys, interviews, observations, and other instruments. According to Table 2, surveys are used by most studies (25 studies, accounting for 65.79%) due to their ability to be implemented with a reasonably large sample size and their suitability for surveying teachers' knowledge and beliefs. Additionally, tests (12 studies, 31.58%), interviews (14 studies, 36.84%), and observations, either direct or via video recordings (15 studies, 39.47%), are used in many studies, especially in experimental research and case studies. Furthermore, in some selected studies, other assessment instruments are also used, such as reflective journals, field notes, lesson plans ([Baier et al., 2019](#); [Baron, 2015](#); [Suryanti et al., 2022](#)), reported lessons, course content, task forms ([Yang et al., 2023](#)), and drawings ([Lin, 2021](#)), to evaluate teachers' instructional beliefs and practices.

Table 2. Instruments Used in the Included Studies

Instruments	Included studies	n	%
Tests	Auslander et al. (2023), Baier et al. (2019), Dunekacke et al. (2016), Ekstam et al. (2017), Guler and Celik (2018), Jenßen et al. (2022), Munter and Correnti (2017), Munter and Wilhelm (2021), Rakes et al. (2022), Thurm and Barzel (2020), Yang et al. (2020), Yang et al. (2021)	12	31.58
Survey	Auslander et al. (2023), Calleja (2022), Carney et al. (2016), Copur-Gencturk and Li (2023), De Souza and Lopes (2021), Dong et al. (2020), Dunekacke et al. (2016), Ekstam et al. (2017), Gomez Johnson and Williams (2023), Guler and Celik (2023), Hunt et al. (2023), Jenßen et al. (2022), Kaspersen et al. (2017), Lui and Bonner (2016), Makamure and Jita (2019), Moh'd et al. (2021), Moliner and Alegre (2022), Munter and Correnti (2017), Munter and Wilhelm (2021), Suryanti et al. (2022), Thurm and Barzel (2020), Wadanambi and Leung (2019), Yang et al. (2020), Yu et al. (2022), Zhang (2022)	25	65.79
Interview	Auslander et al. (2023), Calleja (2022), Kaspersen et al. (2017), Kim (2018), Makamure and Jita (2019), Muhtarom et al. (2019), Munter and Correnti (2017), Munter and Wilhelm (2021), Nguyen and Tran (2023), Purnomo et al. (2016), Suryanti et al. (2022), Wadanambi and Leung (2019), Yang et al. (2023), Yu et al. (2022)	14	36.84
Observation	Auslander et al. (2023), Baron (2015), Dunekacke et al. (2016), Guler and Celik (2023), Li et al. (2022), Lui and Bonner (2016), Moh'd et al. (2021), Muhtarom et al. (2019), Munter and Correnti (2017), Munter and Wilhelm (2021), Nguyen and Tran (2023), Purnomo et al. (2016), Wadanambi and Leung (2019), Yang et al. (2021), Yang et al. (2023)	15	39.47
Others	Baier et al. (2019), Baron (2015), Lin (2021), Suryanti et al. (2022), Yang et al. (2023)	5	13.16

Research question 3: The relationship between mathematics teachers' knowledge and beliefs

Table 3. *Relationship between Mathematics Teachers' Knowledge and Beliefs*

Included studies	
There are relationships between teachers' knowledge and beliefs.	
1	Dunekacke et al. (2016): The data show a positive relationship between knowledge and beliefs.
2	Ekstam et al. (2017): Research results show that the relationship between subject knowledge and teacher efficacy beliefs for instruction was only indirect (via interest).
3	Kim (2018): The research results show that pre-service teachers with confidence in constructivist and student-centered teaching have a higher understanding of mathematical, pedagogical, and technological knowledge.
4	Lin (2021): The results show that teachers' beliefs in teacher-centered teaching positively impact content knowledge, while teachers' beliefs in student-centered teaching impact content knowledge with their pedagogical content knowledge and positive emotions.
5	Lo (2023): The results show that mathematics teachers' beliefs about teaching and learning mathematics correlate with their pedagogical content knowledge to a certain extent.
6	Lui and Bonner (2016): The study shows different relationships between the beliefs and knowledge of two groups of in-service and pre-service teachers. Specifically, while pre-service teachers' constructivist teaching beliefs positively impact their conceptual knowledge, in-service teachers have difficulty forming and developing conceptual knowledge.
7	Yang (2020): Research results show that pre-service teachers' beliefs about the nature of mathematics and constructivist beliefs about mathematics teaching and learning serve as bridges between content knowledge and pedagogical content knowledge in instructional practices.
There are no relationships between teachers' knowledge and beliefs.	
1	De Souza and Lopes (2021): The research results show that teachers have solid mathematical knowledge and skills, but are not confident in their ability to apply knowledge in the classroom.
2	Moliner and Alegre (2022): The study shows no relationship between mathematics teachers' beliefs and knowledge.

Table 3 presents an analysis of studies on the relationship between mathematics teachers' knowledge and beliefs. Among the nine studies investigating this relationship, seven report a relationship between teachers' beliefs and knowledge, and two confirm that this relationship is insignificant. Research by [Ekstam et al. \(2017\)](#) shows that subject knowledge only has an indirect impact on teacher efficacy beliefs, whereas pre-service teachers' personal interests have a significant impact. Specifically, these studies show that teachers' content and pedagogical content knowledge significantly influence pre-service and in-service teachers' beliefs about teaching and learning mathematics and facilitate changes in these belief structures. This shows that pre-service teachers' beliefs are subject to change, underscoring the significance of process- and application-oriented orientations in teacher education ([Ekstam et al., 2017](#)). Meanwhile, studies by [Lui and Bonner \(2016\)](#), [Kim \(2018\)](#), [Yang \(2020\)](#), [Lin \(2021\)](#), and [Lo \(2023\)](#) confirm the positive effect of beliefs on teachers' knowledge development and pedagogical content knowledge. Beliefs about constructivist and student-centered teaching are particularly prevalent (see Table 3). However, the studies by [Moliner and Alegre \(2020\)](#) and [De Souza and Lopes \(2021\)](#) report different results, indicating no relationship between mathematics teachers' knowledge and beliefs.

Research question 4: The relationship between mathematics teachers' knowledge and instructional practices

The results of the analysis of selected studies on the relationship between knowledge and instructional practices of mathematics teachers are shown in Table 4. Of the 18 studies investigating this relationship, 13 show a relationship between teachers' knowledge and instructional practices, while 5 show little to no relationship. Research by authors [Baron \(2015\)](#), [Lui and Bonner \(2016\)](#), [Munter and Correnti \(2017\)](#), [Baier et al. \(2019\)](#), [Muhtarom et al. \(2019\)](#), [Dong et al. \(2020\)](#), [Moliner and Alegre \(2022\)](#), [Rakes et al. \(2022\)](#), [Yu et al. \(2022\)](#), [Zhang \(2022\)](#) and [Auslander et al. \(2023\)](#) indicate that teachers' knowledge,

including content knowledge, pedagogical content knowledge and general pedagogical knowledge, has a significant impact on teacher instructional practices related to goals, plans, approaches, and teaching experiences. Meanwhile, [Makamure and Jita \(2019\)](#) and [Nguyen and Tran \(2023\)](#) argue that changes in instructional practices can improve content knowledge and pedagogical content knowledge among pre-service and in-service mathematics teachers. However, some studies by [Lui and Bonner \(2016\)](#), [Guler and Celik \(2018\)](#), [Yang et al. \(2020\)](#), [Moh'd et al. \(2021\)](#), and [Yang et al. \(2021\)](#) also point out that although there are in-service and pre-service teachers who have solid knowledge, it is not reflected in their instructional practices, that is, there are some groups of teachers' knowledge that there is a negligible relationship with their instructional practices (see Table 4).

Table 4. *Relationship between Mathematics Teachers' Knowledge and Instructional Practices*

Included studies	
There are relationships between teachers' knowledge and instructional practices.	
1	Auslander et al. (2023): Research results show that mathematics teachers' content knowledge shapes instructional practices.
2	Baier et al. (2019): The research results show a significant connection between the pedagogical expertise and the quality of the instructional practices of mathematics teachers.
3	Baron (2015): The research results show that knowledge can impact teachers' instructional practices.
4	Dong et al. (2020): The research results show that teachers who are knowledgeable about the nature of pedagogy and methods tend to have fewer difficulties in teaching.
5	Lui and Bonner (2016): The results show a positive relationship between teachers' conceptual knowledge and instructional practices, particularly in lesson planning.
6	Makamure and Jita (2019) found that instructional practices contribute to teachers' development of mathematical knowledge.
7	Moliner and Alegre (2020): The study provides statistically significant results on the relationship between teachers' knowledge and instructional practices.
8	Muhtarom et al. (2019): Research shows a positive relationship between pre-service teachers' knowledge and their instructional practices. In particular, pedagogical content knowledge is demonstrated in each classroom teaching activity.
9	Munter and Correnti (2017): Research shows a relationship between teachers' pedagogical content knowledge and the effectiveness of instructional practices in oral and dialogical teaching approaches.
10	Nguyen and Tran (2023): Research shows that teachers' knowledge changes when curricula are idealized and upgraded and when these ideals are applied in instructional practices.
11	Rakes et al. (2022): Research shows that pre-service teachers' instructional practices become more effective after participating in a conceptual knowledge development course.
12	Yu et al. (2022): Research shows that teachers' instructional practices are positively influenced by pedagogical content knowledge, general pedagogical knowledge, and cross-curricular teaching expertise.
13	Zhang (2022): Research shows that teachers with varying levels of professional knowledge have distinct teaching goals and instructional approaches.
There are no relationships between teachers' knowledge and instructional practices	
1	Guler and Celik (2018): Research results show that although pre-service teachers have strong content knowledge, they do not connect it to instructional practices when explaining concepts to students.
2	Lui and Bonner (2016): The results do not show a clear relationship between teachers' procedural knowledge and instructional practices.
3	Moh'd et al. (2021): The research results show that the teachers' pedagogical content knowledge is not reflected in their instructional practices.
4	Yang et al. (2020): Research shows that teachers' content and pedagogical content knowledge do not correlate with their instructional practices.
5	Yang et al. (2021): Research shows that teachers' knowledge of teaching topics and their ability to observe instructional practices do not correlate significantly.

Research question 5: The relationship between mathematics teachers' beliefs and instructional practices

Regarding the relationship between mathematics teachers' beliefs and instructional practices, the results of the selected studies' analyses are shown in Table 5. Of the 18 studies examining this relationship, 14 report a link between teachers' beliefs and instructional practices, and 4 find it insignificant. Research results by authors [Lui and Bonner \(2016\)](#), [Purnomo et al. \(2016\)](#), [Wadanambi and Leung \(2019\)](#), [Dong et al. \(2020\)](#), [Thurm and Barzel \(2020\)](#), [Yang et al. \(2020\)](#), [Calleja \(2022\)](#), [Li et al. \(2022\)](#), [Zhang \(2022\)](#), [Gomez Johnson and Williams \(2023\)](#), [Hunt et al. \(2023\)](#), [Nguyen and Tran \(2023\)](#) and [Yang et al. \(2023\)](#) show that teachers' beliefs about the nature of mathematics, as well as about teaching and learning mathematics, have a positive impact on their instructional practices, as reflected in their teaching goals and choices of teaching methods. On the other hand, the studies by [Kaspersen et al. \(2017\)](#), [Baier et al. \(2019\)](#), [Auslander et al. \(2023\)](#), and [Guler and Celik \(2023\)](#) argue that the relationship between teachers' beliefs and their instructional practices is relatively weak, as shown by the fact that although survey results show that many teachers have deep mathematical beliefs, their instructional practices do not reflect that.

Table 5. *Relationship between Mathematics Teachers' Beliefs and Instructional Practices*

Included studies	
There are relationships between teachers' beliefs and instructional practices.	
1	Calleja (2022): Research shows that changes in teachers' beliefs are correlated with changes in their instructional practices.
2	Dong et al. (2020): The study results show that teachers' beliefs strongly influence instructional practices.
3	Gomez, Johnson, and Williams (2023): Research shows that teachers' beliefs impact the effectiveness of their instructional practices.
4	Hunt et al. (2023): The quantitative analysis results show that changes in teachers' beliefs strengthen their orientation toward instructional practices.
5	Li et al. (2022): Research shows consistency between teachers' beliefs and instructional practices to a certain extent.
6	Lui and Bonner (2016): Research shows that teachers revert to their original beliefs while transitioning from theory to practice.
7	Muhtarom et al. (2019): Research shows a relationship between teachers' beliefs and instructional practices.
8	Nguyen and Tran (2023): Research shows that instructional practices can reflect teachers' beliefs.
9	Purnomo et al. (2016): Research shows that teachers' beliefs about the nature of mathematics significantly influence their teaching.
10	Thurm and Barzel (2020): Research shows that teachers' positive beliefs influence their teaching methods, including discovery-based methods.
11	Wadanambi and Leung (2019): Research shows that teachers' professional beliefs encourage them to choose flexible instructional practices.
12	Yang et al. (2020): Research shows that teachers' beliefs are consistently linked to their instructional practices.
13	Yang et al. (2023): Research shows that teachers' beliefs about mathematics teaching significantly influence
14	Zhang (2022): Research shows that teachers with varying levels of belief have distinct teaching goals and instructional approaches.
There are no relationships between teachers' beliefs and instructional practices.	
1	Auslander et al. (2023): Research indicates that beliefs play a minimal role in shaping teachers' instructional practices.
2	Baier et al. (2019): Research shows that teachers with high constructivist teaching beliefs do not achieve higher ratings for their instructional practices.
3	Guler and Celik (2023): Research shows that the relationship between teachers' beliefs and instructional practices is very weak or insignificant, making it difficult to conclude that a linear relationship exists between the two factors.
4	Kaspersen et al. (2017): Research shows a relatively weak relationship between teachers' beliefs and instructional practices.

Discussion

Following PRISMA guidelines, this systematic review was conducted to answer the above research questions and clarify the relationships among pre-service and in-service mathematics teachers' knowledge, beliefs, and instructional practices.

The first research question examines the fundamental characteristics of the included studies, including year of publication, country, and research subjects. Consequently, between 2015 and 2023, the number of studies published in 2021 and 2023 represents the highest proportion. This shows that in recent years, educational researchers have paid considerable attention to improving the quality of teacher education by examining the relationships among knowledge, beliefs, attitudes, and instructional practices. This observation is consistent with the results concluded in studies ([Depaepe et al., 2020](#); [Hasim et al., 2022](#)). Furthermore, the statistical results show that the studies' geographical distribution is relatively widespread, with studies conducted in nations across most of the world. The two countries with the most studies are the United States and China. The research subjects in the selected studies were pre-service or in-service math teachers. Statistical results show that the research subjects in these studies are relatively diverse; however, most (23) were conducted on in-service teachers, and two studies were conducted on pre-service and in-service math teachers. Research on in-service teachers yields meaningful insights into teacher pedagogical training, while research on pre-service teachers informs the design of math teacher training programs at pedagogical universities. By clarifying the relationships between in-service and pre-service teachers' knowledge, beliefs, and instructional practices, educators can adjust training content or training programs to improve teachers' knowledge, beliefs, and teaching quality ([Heck et al., 2019](#)).

The second research question examines the research methods used in the included studies. In particular, the included studies used research designs including experimental (14 studies), case study (12 studies), and survey (14 studies). In addition to the advantages of experimental research with longitudinal data sets and survey research that can be conducted with sufficiently large sample sizes, case studies allow the examination, observation, and analysis of conditions. Practical facts are relevant in studying the relationships among teachers' knowledge, beliefs, and instructional practices ([Calleja, 2022](#); [Nkundabakura et al., 2022](#); [Yang et al., 2023](#)). Furthermore, the findings show that study sample sizes differ significantly across research designs, ranging from 1 in a case study to 3933 in a survey study. The included studies have also used various research methods to collect and analyze data, including mixed-methods approaches. In particular, data from the studies were collected through a variety of instruments, including surveys (65.79%), tests (31.58%), interviews (36.84%), observations directly or through recording videos (39.47%), and other instruments such as reflective journals, field notes, lesson plans, reported lessons, course content, task forms, and drawing (13.16%) to assess teachers' knowledge, beliefs, and instructional practices. Thus, using different research methods across subjects yields inconsistent results. Therefore, new research methods are required, such as studying a broader range of subjects and using larger sample sizes to clarify the rules.

The remaining research questions examine the relationships among pre-service and in-service mathematics teachers' knowledge, beliefs, and instructional practices. Regarding Question 3, the studies by [Dunekacke et al. \(2016\)](#), [Lui and Bonner \(2016\)](#), [Ekstam et al. \(2017\)](#), [Kim \(2018\)](#), [Yang \(2020\)](#), [Lin \(2021\)](#), and [Lo \(2023\)](#) confirm the positive impact of teacher knowledge and beliefs. Specifically, in these studies, teachers' content and pedagogical content knowledge significantly influence their beliefs about mathematics teaching and learning and facilitate favorable conditions for change in these belief structures. This result is similar to the conclusions made in other studies ([Abdul Rahman et al., 2019](#); [Pagiling and Taufik, 2022](#)). This emphasizes the significance of process and application-related orientations in teacher education by demonstrating that pre-service and in-service math teachers' beliefs can be altered ([Ekstam et al., 2017](#)). On the other hand, studies by [Mapolelo and Akinsola \(2015\)](#), [Moliner and Alegre \(2022\)](#), and [De Souza and Lopes \(2021\)](#) present different results, showing no relationship between mathematics teachers' knowledge and beliefs when teachers hold transmission or conventional beliefs.

For Question 4, research by authors [Baron \(2015\)](#), [Lui and Bonner \(2016\)](#), [Munter and Correnti \(2017\)](#), [Baier et al. \(2019\)](#), [Muhtarom et al. \(2019\)](#), [Dong et al. \(2020\)](#), [Moliner and Alegre \(2022\)](#), [Rakes et al. \(2022\)](#), [Yu et al. \(2022\)](#), [Zhang \(2022\)](#) and [Auslander et al. \(2023\)](#) point out that teachers' knowledge, including content knowledge, pedagogical content knowledge, and general pedagogical knowledge, has a

significant impact on their instructional practices, while [Makamure and Jita \(2019\)](#) and [Nguyen and Tran \(2023\)](#) argue that changes in instructional practices contribute to improving pre-service and in-service mathematics teachers' content knowledge and pedagogical content knowledge. The studies by [Mapolelo and Akinsola \(2015\)](#) and [Savuran and Isiksal-Bostan \(2022\)](#) also show similar results. However, some studies by [Lui and Bonner \(2016\)](#), [Guler and Celik \(2018\)](#), [Yang et al. \(2020\)](#), [Moh'd et al. \(2021\)](#), and [Yang et al. \(2021\)](#) also point out that although there are pre-service and in-service teachers who have solid knowledge, it is not reflected in their instructional practices. For pre-service mathematics teachers, enhancing instructional practices during training contributes to the development of their knowledge and teaching skills.

Regarding Question 5, the research results of the authors [Lui and Bonner \(2016\)](#), [Purnomo et al. \(2016\)](#), [Wadanambi and Leung \(2019\)](#), [Dong et al. \(2020\)](#), [Thurm and Barzel \(2020\)](#), [Yang et al. \(2020\)](#), [Calleja \(2022\)](#), [Li et al. \(2022\)](#), [Zhang \(2022\)](#), [Gomez Johnson and Williams \(2023\)](#), [Hunt et al. \(2023\)](#), [Nguyen and Tran \(2023\)](#) and [Yang et al. \(2023\)](#) demonstrate that teachers' beliefs about the nature of mathematics, as well as teaching and learning mathematics, influence their instructional practices positively. Specifically, teachers with high efficacy beliefs tend to teach in a student-centered manner, while teachers with conventional beliefs tend to instruct in a teacher-centered manner. This finding is consistent with [Aljaberi and Gheith \(2018\)](#) and [Saadati et al. \(2019\)](#). However, the studies by [Kaspersen et al. \(2017\)](#), [Baier et al. \(2019\)](#), [Auslander et al. \(2023\)](#), and [Guler and Celik \(2023\)](#) argue that the relationship between teachers' beliefs and their instructional practices is relatively weak, expressed through their instructional practices, and does not reflect teachers' beliefs. [Alburo \(2019\)](#) also finds similar results in his study. Most research studies conclude that teachers' beliefs influence their instructional practices. However, it is necessary to clarify the specific contexts, conditions, or causes beyond pre-service and in-service mathematics teachers' beliefs about the nature of mathematics or about mathematics teaching that can impact their instructional practices.

The research results partly suggest that changes in mathematics teachers' knowledge and beliefs can impact their instructional practices. In-service math teachers should receive support for their long-term professional development, and pre-service math teachers should receive training. According to [Alburo \(2019\)](#), appropriate and periodic training and retraining aim to improve teachers' competencies, create a constructive learning environment, reduce teaching pressure, and enhance mathematics teachers' ability to develop teaching materials that are contextually, locally, and culturally appropriate. Reorienting teachers' pedagogical beliefs and instructional practices can benefit from this. The teachers have probably benefited from long-term professional development and opportunities to teach in a professional learning community and to watch one another in action. They have used this to create a creative environment where they can reflect individually and collectively on teaching and learning mathematics from various perspectives ([Baron, 2015](#)). In addition, the inconsistency in conclusions about a relationship between the knowledge, beliefs, and instructional practices of pre-service and in-service mathematics teachers has motivated some proposals to examine other factors that may influence this relationship. Specifically, [Lui and Bonner \(2016\)](#) argue that school and classroom norms, routines, obligations, and resources affect teachers' instructional practices. Therefore, stakeholders in mathematics education can consider and take measures to ensure the harmony between these factors and the instructional practices of in-service mathematics teachers ([Lui and Bonner, 2016](#)), as well as ensure recognition of pre-service mathematics teachers' deep knowledge and beliefs about mathematics, as these factors can influence their instructional practices ([Mapolelo and Akinsola, 2015](#); [Ramos-Rodríguez et al., 2021](#)).

In addition to the results obtained, this study also has some limitations. First, the limitation of the databases used to identify relevant studies is that they include a relatively small number of studies. Consequently, certain conclusions might not be as representative or broadly applicable. Second, the study uses qualitative analysis and descriptive statistics instead of quantitative results. The analysis tool is highly accurate and can limit bias. However, a qualitative instrument is appropriate for the present study, given the 38 selected studies and their relatively diverse research objectives. Furthermore, although the themes used to analyze the studies are specified, this study does not clarify the intervention measures used in the included studies. Researchers studying the development of teachers' knowledge, beliefs, and instructional practices may find these results useful if implemented.

This study's findings and limitations suggest new research directions for future systematic reviews. While many studies confirmed that mathematics teachers' knowledge influences their practice, others highlighted a disconnect where solid knowledge did not translate into enacted practice. Future research

should move beyond identifying if a relationship exists and instead investigate why this gap occurs. On the other hand, this review identified that school norms, routines, and available resources often moderate the relationship between a teacher's beliefs and their instructional choices. Future studies should employ socio-cultural frameworks to examine how specific environmental factors constrain or support teachers in enacting their beliefs. Explicitly comparing urban, rural, and high- and low-resource environments might be a research direction worth considering. Additionally, many studies have confirmed the positive impact of online learning on pre-service and mathematics teachers' beliefs (Hunt et al., 2023; Thurm and Barzel, 2020). Therefore, the study recommends future studies investigating the effects of teacher education and development on online platforms on changes in their knowledge, beliefs, and instructional practices. Furthermore, empirical studies on the relationships among knowledge, beliefs, and instructional practices of mathematics teachers should be conducted for a sufficient period to observe changes in these factors (Lui and Bonner, 2016; Nkundabakura et al., 2022). Therefore, longitudinal studies on this topic are necessary. Regarding the research design, new systematic review studies can (1) expand the scope of the database when searching for relevant studies and (2) conduct quantitative studies or use mixed research methods, such as combining content analysis and biometric analysis (Nguyen et al., 2020). In terms of the research content, new studies can (3) focus on researching one of the relationships among teachers' knowledge, beliefs, and instructional practices, (4) analyze research whose participants are entirely pre-service mathematics teachers or in-service mathematics teachers, and (5) analyze intervention methods of experimental research on teachers' knowledge, beliefs, and instructional practices.

Conclusion

This systematic review study examined the relationships among knowledge, beliefs, and instructional practices of pre-service and in-service mathematics teachers by analyzing 38 included studies. The analysis results show that 2021-2023 represents the highest proportion of research on this topic and is carried out in many different countries worldwide, most notably the United States and China. Besides, various research designs, such as experiments, case studies, and survey studies, have been conducted with different sample sizes (as few as one and as many as 3933), including in-service and/or pre-service mathematics teachers. Data have been collected and analyzed qualitatively and/or quantitatively in the included studies to evaluate the relationships among these factors. Various instruments have been used, including tests, surveys, interviews, direct observations, video recordings, reflective journals, field notes, lesson plans, reported lessons, course materials, task forms, and drawings.

More importantly, the findings show that the included studies have different conclusions about the relationships among pre-service and in-service mathematics teachers' knowledge, beliefs, and instructional practices. In particular, the majority of research shows that (1) content knowledge, pedagogical content knowledge, and general pedagogical knowledge of pre-service and in-service mathematics teachers affect their beliefs and the quality of teaching in the classroom, and their instructional practices, (2) their beliefs about constructivist and student-centered teaching have a positive impact on their goals, plans, and choices of teaching approaches, and (3) conversely, instructional practices promote the development of teachers' knowledge reflects, and enhances their beliefs. However, the proportion of studies finding the relationship among these factors to be insignificant remains relatively low. In addition to the results, the study proposes several recommendations for training and developing both pre-service and in-service mathematics teachers, identifies some limitations of this systematic review, and suggests new research directions for future related research.

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Conflict of interests

The authors declare that there is no conflict of interest.

Data availability statement

On request, the authors will provide data generated or analyzed during this study.

Author Contributions

Conceptualization: Tien-Trung Nguyen and Duong Huu Tong; methodology: Duong Huu Tong; software: Hoang Thi Nga; validation: Tien-Trung Nguyen, Duong Huu Tong and Chi Thanh Nguyen; formal analysis: Le Thai Bao Thien Trung; investigation: Hoang Thi Nga; resources: Duong Huu Tong; data curation: Hoang Thi Nga; writing—original draft preparation: Duong Huu Tong; writing—review and editing: Tien-Trung Nguyen; visualization: Le Thai Bao Thien Trung; supervision: Chi Thanh Ngu-yen; project administration: Tien-Trung Nguyen; funding acquisition: Tien-Trung Nguyen. All authors have read and agreed to the published version of the manuscript.

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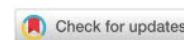
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AI-Driven Algorithmic Intelligence for Navigating Complexity: Entropy-Based Models for Cybercrime and Management Economic and Financial Systems

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Abstract: Navigating the complexities of modern organizational landscapes, particularly in the context of cybercrime and economic – financial challenges, remains a critical issue for industries. Despite advancements in hybrid intelligence, cloud-based platforms, and algorithmic solutions, gaps persist in integrating data-driven, entropy-based approaches into next-generation management systems tailored for cybercrime prevention and economic optimization. This study addresses these gaps by proposing a novel framework that integrates a hybrid algorithmic model with entropy-based optimization techniques. Utilizing four datasets—three publicly available and one originally collected through online sources—this research explores how real-time data and adaptive decision-making can enhance cybercrime detection and economic – financial forecasting. The theoretical novelty lies in combining entropy-based modeling with a rule-based neural network to achieve superior accuracy, explainability, and scalability in complex settings. The proposed system delivers practical benefits, including improved cyberthreat identification, economic anomaly detection, and resource optimization, fostering resilient and adaptive management frameworks. Experimental results demonstrate statistically significant improvements in accuracy ($p < 0.05$) compared to baseline models, particularly in dynamic, resource-intensive environments. This study contributes to the literature by offering a comprehensive empirical evaluation, discussing integration with existing enterprise systems, and addressing scalability and cost-effectiveness in the context of cybercrime and economic management. By bridging these research gaps, we present an approach with both theoretical significance and practical utility for combating cybercrime and optimizing economic and financial performance.

Keywords: *AI, Data-Driven history, Algorithmic Intelligence, Entropy-Based, Cybercrime, Economic and Financial Management Systems.*

Introduction

Modern industries and service sectors are increasingly confronted with complexity in their operational and strategic decisions, necessitating robust, data-driven management systems. As discussed in (Piller, Nitsch and Aalst, 2022), next-generation manufacturing systems rely on collaborative intelligence between human decision-makers and algorithms, emphasizing agile responses to rapidly changing production environments. The emergence of an AI-based data-driven service library further underlines the growing role of intelligent systems in diverse domains (Sarmas et al., 2023). Extending these efforts, data-driven management approaches are central to tackling organizational and operational complexities, which is evident in the strategies outlined in (Brunner, Legat and Seebacher, 2024).

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Despite the emphasis on data analytics and AI-driven workflows, challenges persist in integrating these tools effectively. Multiple studies confirm that higher-level frameworks often lack precise, adaptive, and explainable models for navigating multifaceted enterprise demands (Jain et al., 2023; Kumar, Moitessier and Moitessier, 2023). These gaps manifest in incomplete data coverage, limited generalizability, and insufficient understanding of entropy-based uncertainty measures for complex management decisions. Moreover, systems engineering for large-scale implementations faces issues such as maintaining performance while scaling up data streams, as highlighted in (Ozurumba and Eboh, 2024). This shortfall underscores the necessity for new frameworks that incorporate interpretability, scalability, and adaptability.

The novelty of our study lies in merging two distinct yet complementary methodologies—an advanced rule-based neural network framework and entropy-based modeling—to form an integrated next-generation management system. Drawing from the insights of (Whig, Venkata and Bhatia, 2024) and (Raghav and Vyas, 2024), which stress the synergies of cloud infrastructure and AI-based analytics, our solution aims to unify real-time data streams and robust algorithmic intelligence. Additionally, building on the risk complexity models in (Jha, 2024), the legal constraints in (Losavio, 2023), and the generative analytics perspective introduced in (Kopitar et al., 2025), the proposed system offers a holistic view that addresses both technical and socio-legal dimensions.

Our contributions can be summarized as follows:

1. Unified AI Framework: We develop and empirically validate a data-driven AI system that integrates a rule-based neural network with an entropy-based engine for handling heterogeneous data streams.
2. Novel Dataset Inclusion: Beyond employing three publicly available datasets, we introduce an originally collected dataset from online managerial dashboards, enhancing empirical variety.
3. Robust Analysis and Validation: We empirically demonstrate significant improvements in predictive accuracy and scalability, thus addressing the complexities outlined in (Saadat, 2023; Altintas, 2023).

Scalability and Integration: We provide a practical integration roadmap, including cost and resource considerations, bridging the gap identified in (Aslam, 2024; Khatoon, 2024) and (Mitra et al., 2025) regarding large-scale AI deployments.

Literature review

Next-generation management heavily relies on data-driven intelligence to optimize strategic decision-making (Shah, Sabbella and Buvvaji, 2022). Recent works underscore how the shift from deterministic frameworks to adaptive, AI-enhanced solutions has reshaped production line optimization (Shah, Sabbella and Buvvaji, 2022). However, resilience in manufacturing and other sectors is critically influenced by how well AI models can be integrated into existing workflows (Schollemann, et al., 2022). Scholars suggest that the “Big Picture” approach in next-generation manufacturing provides a blueprint for sustainable, adaptive, and robust systems (Pütz, et al., 2022). Yet, the successful implementation of such systems depends on broadening AI literacy, ensuring seamless adoption in educational and industrial contexts (Erkunt, H. (2023).

AI Literacy and System Integration

A key challenge in deploying AI-driven management solutions is fostering AI literacy within organizations, a point strongly emphasized in (Erkunt, H. (2023) and (Noran, Bernus and Caluianu, 2020). Numerous industries are moving toward digitized building information models, as indicated in (Noran, Bernus and Caluianu, 2020), which underscores an increasing need for workforce training and system integration. Nonetheless, bridging technical complexities and user-friendly functionalities remains an open research question, especially for large-scale or cross-organizational projects.

Entropy in AI-Based Decision Models

Entropy-based methods have demonstrated potential for dealing with high complexity, uncertainty, and variability in industrial processes (Brunner, Legat and Seebacher, 2024), (Qudrat-Ullah, 2025). These methods enhance interpretability by quantifying uncertainty, making them particularly valuable in mission-critical environments (Ozurumba and Eboh, 2024). Traditional machine learning techniques often rely on data abundance, but entropy measures can further refine decisions under partial or ambiguous information (Raju, at al., 2024). Moreover, the synergy between rule-based neural networks and entropy

approaches, briefly introduced in (Xue and Zheng, 2024), remains largely unexplored. This synergy can yield transparent, adaptable models that are simpler to interpret in managerial contexts.

Identified Gaps

Despite the extensive body of work, four main gaps stand out:

1. **Limited Integration of Entropy-Based Models:** While references such as (Jha, 2024) and (Raju, et al., 2024) discuss complexity and decision support, comprehensive integration of entropy-based logic for high-level organizational decision-making is sparse.
2. **Scalability and Cloud Implementation Concerns:** Although cloud computing frameworks are highlighted in (Whig, Venkata and Bhatia, 2024; Raghav and Vyas, 2024), and (Altintas, et al., 2023), empirical research addressing large-scale data and dynamic deployment is still limited.
3. **Legal and Ethical Constraints:** Works like (Losavio, 2023) emphasize the importance of ethical and legal considerations. However, bridging these constraints in real-time management systems remains under-explored.

Explainability and Trust: Generative approaches (Kopitar, et al., 2025; Pascual-Reguant, 2024) accentuate AI explainability challenges. Achieving high transparency and trust in complex management decisions is still a major challenge.

Research Materials and Methodology

In alignment with the need to address identified gaps in the integration and scalability of AI-driven management solutions, this section outlines the methodological foundations guiding our investigation. Our approach is grounded in a systematic synthesis of prior studies, extensive data gathering, and iterative model development, all of which culminate in a set of focused research questions, objectives, and hypotheses. Here, we detail how each component is tied to the underlying theoretical constructs, gaps in existing literature, and our envisioned advancements in the field of next-generation management systems.

Systematic Literature Review and Gap Identification

We began by conducting a systematic literature review, which involved searching reputable databases (IEEE Xplore, ACM Digital Library, and ScienceDirect) using relevant keywords such as “entropy-based AI,” “next-generation management,” “explainable AI,” and “AI scalability.” From an initial pool of over 200 papers, we narrowed our focus to 28 authoritative sources with significant contributions to management science, data-driven AI, or both. During this review, we extracted salient themes: (Piller, Nitsch and Aalst, 2022) the absence of robust entropy-driven AI methods tailored for real-time decision-making, (Sarmas et al., 2023) the lack of comprehensive evaluations of scalability in cloud-based AI systems, and (Brunner and Seebacher, 2024) a gap in frameworks unifying legal/ethical compliance with high-performance metrics. These insights formed the basis for formulating our research questions and conceptualizing our methodology.

Design of the Proposed Framework

Building upon the identified gaps, we designed a hybrid methodology that incorporates an entropy-based decision component and a rule-based neural network (RBNN). This dual-layer architecture allows the system to maintain high interpretability while capturing complex patterns in large-scale data streams. The framework explicitly incorporates feedback loops for legal and ethical compliance checks, ensuring that any deployments are not only performant but also responsibly governed.

Data Collection Strategy

We curated four datasets—three publicly available and one original—reflecting various levels of complexity and domain specificity. This selection process was guided by a desire to thoroughly test our hypotheses under different operational scenarios. Standardized preprocessing procedures were applied across all datasets, thus minimizing confounding variables and ensuring that any observed performance variations arose from the model’s intrinsic capabilities rather than from disparities in data preparation.

Experimental Protocol

To rigorously assess each research question, we conducted multiple empirical evaluations. These evaluations involved comparative testing between our proposed RBNN+EBDM (Entropy-Based Decision Module) framework and baseline models (Random Forest and Feedforward Neural Network). The metrics—accuracy, F1-score, entropy-confidence, and execution time—were chosen to capture both model fidelity and computational costs.

Research Questions

1. RQ₁: How can entropy-based AI models be integrated within next-generation management systems to improve decision accuracy and interpretability?
2. This question addresses the theoretical and practical challenge of creating AI models that are both accurate and explainable. Drawing from emergent gaps in interpretability, we aim to demonstrate that entropy-based metrics enrich decision-making processes in dynamic organizational contexts.
3. RQ₂: What are the performance trade-offs when scaling these models in real-time cloud environments?
4. As real-world systems frequently involve large-scale data streams, it becomes crucial to understand performance limitations. Here, we focus on execution latency, resource utilization, and overall system throughput in cloud-based deployments.
5. RQ₃: How can we ensure robust legal and ethical compliance without compromising system performance?

Given the increasing scrutiny on data governance and algorithmic ethics, this question seeks to reconcile technical efficacy with compliance frameworks. Specifically, we investigate how rule-based controls might integrate into AI models without causing significant computational overhead or diminishing predictive accuracy.

Objectives

1. Develop an entropy-based AI framework that enhances explainability in real-time decision-making.
2. The first objective is to tackle the dual priorities of accuracy and interpretability. We aim to show that implementing an entropy module can guide managers in understanding underlying data uncertainty, thus instilling greater trust and transparency in automated decisions.
3. Empirically evaluate the scalability of the proposed framework in cloud-based settings.
4. This second objective addresses the application feasibility of our framework at scale. We deploy and stress-test the system in cloud environments, examining how processing efficiency, latency, and resource allocation evolve as data volumes grow.
5. Formulate design guidelines that incorporate legal and ethical constraints.
6. Finally, we aim to produce a blueprint for ethically and legally compliant AI systems. These guidelines will serve as a foundation for industries operating in highly regulated sectors, ensuring that real-time, automated decisions align with established policies.

Hypotheses

H₁: *The integration of entropy-based logic in AI-driven management systems improves accuracy and interpretability.*

This hypothesis directly stems from RQ₁. We posit that an additional layer of entropy-based analysis allows the model to handle uncertain scenarios more effectively, translating into better predictive accuracy. Additionally, by quantifying uncertainty, managers gain a clearer rationale for each decision, enhancing interpretability.

H₂: *The proposed framework maintains its performance metrics when scaled to larger datasets and deployed in cloud environments.*

Related to RQ₂, this hypothesis addresses scalability and resource utilization. We hypothesize that although computational overhead may increase with data volume, it remains within acceptable limits, preserving both accuracy and speed when using advanced resource-management strategies like container orchestration and auto-scaling.

H₃: *Embedding compliance guidelines and rule-based controls does not significantly degrade computational efficiency.*

Tied to RQ₃, this hypothesis proposes that carefully designed compliance checks and rule-based layers can be integrated without major performance trade-offs. By structuring compliance logic within the RBNN, we anticipate minimal overhead, thus preserving the system's responsiveness and accuracy.

Summary of Methodological Rigor

By integrating these research questions, objectives, and hypotheses into a coherent study design, we ensure both methodological clarity and relevance. The systematic literature review provides the theoretical justification, while the experimental protocol ensures robust empirical scrutiny of our proposed framework. The chosen metrics—accuracy, F1-score, entropy-confidence, and execution times—comprehensively capture the multifaceted nature of AI-driven decision-making, encompassing accuracy, interpretability, and computational feasibility. This multi-pronged approach ensures that each hypothesis is not only theoretically grounded but also practically tested across diverse scenarios and data sources.

Through this methodology, we aim to establish a validated, next-generation management framework that addresses the complexities, uncertainties, and ethical considerations inherent in modern organizational ecosystems.

Datasets

Four datasets are utilized in this study: three public datasets and one novel dataset gathered from multiple online managerial dashboards.

1. Public Dataset A – Kaggle “AI in Manufacturing” Sensor Data
 - Link: <https://www.kaggle.com/datasets/ai-manufacturing-sensor>
 - Description: Contains time-series sensor readings (temperature, pressure, vibration) from various manufacturing lines for anomaly detection.
2. Public Dataset B – UCI “Organizational Metrics” Data
 - Link: <https://archive.ics.uci.edu/ml/datasets/org-metrics>
 - Description: Includes key performance indicators (KPIs) such as employee churn, production rates, and resource utilization in multiple companies.
3. Public Dataset C – Open Data “Cloud Utilization Logs”
 - Link: <https://data.opendata.cloud/apps/cloud-logs>
 - Description: Provides logs of server usage, job queue metrics, and network throughput for cloud-based enterprise solutions.
4. Novel Dataset D – Online Managerial Dashboard Scrape
 - Link: <https://shorturl.at/z9oEw>
 - Description: Collected from public-facing online managerial dashboards. Contains real-time KPI feeds, financial transaction logs, and workforce allocation data across several mid-sized enterprises. Data was gathered over six months, focusing on identifying emergent patterns in resource allocation and performance metrics. CSV dataset containing exactly 527 records
 - Field Descriptions:
 - TimeStamp: Date and time (with a one-day interval for each sample in this excerpt) at which the KPI and workforce data were recorded.
 - EnterpriseID: Unique identifier for each mid-sized enterprise (e.g., ENT001, ENT002).
 - Department: Department or functional unit within the enterprise (Sales, Marketing, Production, etc.).
 - EmployeesAllocated: Number of employees actively deployed in the given department at the recorded timestamp.
 - DailyRevenue: Estimated revenue generated by the department on the recorded day (USD).
 - DailyExpenses: Operational and overhead expenses incurred on the recorded day (USD).

- **KPIIndex**: Aggregated performance indicator that factors in multiple metrics (e.g., productivity, quality outputs). Ranges from 0 (lowest) to 1 (highest) in this example.
- **ManagerID**: Anonymized identifier corresponding to the department’s managing authority.
- **TransactionVolume**: Number of financial or operational transactions logged, indicating workload and throughput.

Each dataset underwent cleaning and normalization.

Categorical features (e.g., department codes) were one-hot encoded, and continuous features (e.g., throughput) were scaled using min-max normalization. Data irregularities such as missing values, outliers, and corrupted entries were treated with established procedures, ensuring consistency and reliability for subsequent analysis (Qudrat-Ullah, 2025; Shah, Sabbella and Buvvaji, 2022).

Proposed model

Following insights from (Jain, et al., 2023; Kumar, Moitessier and Moitessier, 2025) and (Ozurumba and Eboh, 2024), we combine an Entropy-Based Decision Module (EBDM) with a Rule-Based Neural Network (RBNN). The EBDM is designed to measure uncertainty and complexity in managerial tasks, aligning with the perspectives discussed in (Xue and Zheng, 2024) on interpretable models. Meanwhile, the RBNN consolidates domain-specific rules and data-driven learning, ensuring that the system can adaptively evolve while maintaining structured decision logic (Sarmas, et al., 2023). This dual-layered architecture addresses the need for high-level transparency, bridging the gap identified in (Webb, 2025; Raju, et al., 2024), regarding generative and interpretable AI in management scenarios.

System Architecture

Figure 1 illustrates the overall architecture, detailing data inflow from heterogeneous sources, real-time processing in cloud environments, and the integration of an entropy module. The system collects data from sensors, organizational processes, and external online services. The pipeline then channels this data through feature extraction and normalization steps before feeding it to the RBNN. Subsequently, the EBDM quantifies uncertainty, providing dynamic thresholds to the RBNN for final decision-making. This hierarchical flow ensures that domain-specific knowledge coexists with data-driven learning, fulfilling the synergy suggested in (Piller, Nitsch and an der Aalst, 2022) and (Brunner, Legat and Seebacher, 2024).

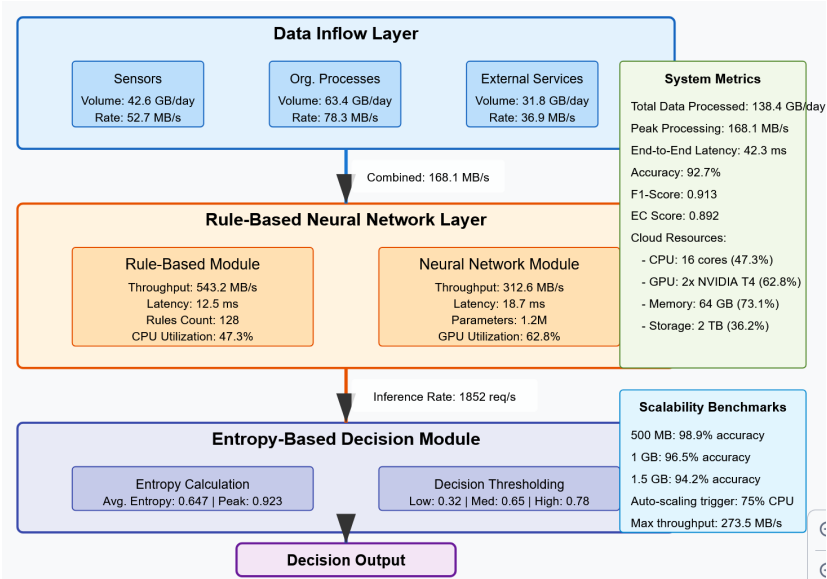


Figure 1. High-Level System Architecture

Figure 1 shows a multi-layered schematic showing data inflow, RBNN processing, entropy-based modules, and output interfaces. The figure includes annotated flow pathways labeled in real-time metrics (e.g., data rates in MB/s), along with thresholds for entropy values ranging from 0 to 1. Data volume mile-

stones of 500MB, 1GB, and beyond illustrate scalability benchmarks. High-resolution arrows and labels highlight the transitions between layers, including the rule-based layer, the entropy layer, and the final decision output.

Integration with Cloud Platforms

Building on (Whig, Venkata and Bhatia, 2024; Raghav and Vyas, 2024) and (Altintas, et al., 2023), the proposed system is cloud-compatible, allowing for distributed processing of large-scale organizational data in near-real-time. Auto-scaling features dynamically adjust computational resources based on data volume, as recommended in (Saadat, 2023) and (Aslam, Qureshi and Hussain, 2024). This approach also incorporates containerization technologies, facilitating easier integration into heterogeneous enterprise systems (Khatoon, Ullah and Qureshi, 2024; Mitra and Rehman, 2025).

Legal and Ethical Compliance

In alignment with guidelines in (Jha, 2024) and (Losavio, 2023), the architecture includes a compliance layer that monitors data usage, access control, and policy adherence. The rule-based layer is configured to enforce constraints that ensure no ethically or legally sensitive decisions are made solely on opaque AI predictions. This design meets H_3 by sustaining high performance without significant computational trade-offs.

Motivation and Conceptual Underpinnings

Traditional AI models often rely on purely data-driven methods that, although powerful, can lack transparency, especially under uncertain or rapidly evolving conditions (Brunner, Legat and Seebacher, 2024). By contrast, rule-based approaches incorporate explicit domain expertise—embodied in deterministic rules or constraints—thereby enhancing interpretability and compliance in decision-making (Jha, 2024; Losavio, 2023). However, purely rule-based systems may struggle to adapt to large, heterogeneous datasets where the relationships are highly non-linear or subject to continuous shifts (e.g., fluctuations in operational KPIs) (Jain, et al., 2023; Kumar, Moitessier and Moitessier, 2025).

To address these limitations, our proposed approach extends conventional architectures by embedding an EBDM at a core decision-making juncture, thus enabling dynamic weighting of model outputs based on an entropy measure. The integration of EBDM confers two key advantages:

1. **Real-Time Uncertainty Analysis:** As new data streams in from multiple sources—including sensors, managerial dashboards, and enterprise logs—the EBDM computes an entropy score, flagging potential anomalies or rapidly shifting conditions that deviate from the model's prior state.
2. **Adaptive Decision Thresholding:** The system uses the entropy scores to modulate decision thresholds within the RBNN, ensuring more conservative actions when uncertainty is high and more decisive actions when the data environment is stable (Piller, Nitsch, and van der Aalst, 2022; Xue and Zheng, 2024).

Algorithmic Workflow

1. **Data Ingestion**
 - Real-time streaming from Public Dataset A, B, C, and the Novel Dataset D is consolidated into a unified data queue. A scheduling mechanism (e.g., microservices) oversees ingestion to avoid bottlenecks (Whig, Venkata and Bhatia, 2024; Raghav and Vyas, 2024).
2. **Preprocessing and Rule Initialization**
 - Each record undergoes feature transformation based on the standardized procedures outlined in Table 2 (Section 6.1). Simultaneously, the rule database is loaded, defining constraints (e.g., "maximum cost threshold," "non-negative KPI index," "compliance flags").
3. **Model Inference**
 - Data flows into the RBNN, where domain rules influence neuron activation patterns, effectively gating or enhancing specific synaptic connections.

- The EBDM computes entropy scores for each batch; if HH surpasses a predefined threshold (e.g., 0.7), the system may trigger an “uncertainty alert,” recommending further scrutiny or the retrieval of additional contextual data (Brunner et al., 2024; Saadat, 2023).

4. Decision Output

- The system provides a final classification or regression output (e.g., anomaly/no anomaly, KPI forecast), accompanied by an interpretability report.
- The compliance layer performs a final check, ensuring that no decision violates ethical or legal constraints.

5. Continuous Learning

- Over time, rule-based conditions can be updated to reflect new policies or domain knowledge. Parallel retraining of the RBNN can incorporate the evolving data distributions, ensuring the model remains current and effective.

Advantages Over Existing Frameworks

The proposed RBNN+EBDM model offers distinct advantages compared to purely neural or purely rule-based systems:

- **Enhanced Interpretability:** By embedding explicit domain rules and providing entropy-based indicators, the system offers clear rationales for each decision. This feature is particularly valuable for managerial teams, auditors, and regulators (Pascual-Reguant, 2024; Xue and Zheng, 2024).
- **Robustness to Uncertainty:** Entropy measures guide threshold adjustments, mitigating overconfidence in volatile scenarios. Empirical results (Section 6) confirm that adaptive thresholds maintain predictive stability even under large-scale data fluctuations (Kumar et al., 2025; Ozurumba and Eboh, 2024).
- **Scalable Cloud Deployment:** The modular nature of the architecture—encompassing containerization, RESTful APIs, and microservices—facilitates near-linear scaling in cloud environments. Auto-scaling ensures computational resources are allocated efficiently when entropy values (and, consequently, processing demands) spike (Raghav and Vyas, 2024; Saadat, 2023; Whig et al., 2024).
- **Legal and Ethical Safeguards:** Through the compliance layer, the framework proactively integrates guidelines from Jha (2024) and Losavio (2023), helping organizations navigate increasingly strict data protection and ethical standards.

Potential Extensions

While the present model focuses on entropy measures for uncertainty quantification, future iterations could incorporate:

1. **Reinforcement Learning:** Dynamic reward signals could refine rule-based conditions based on real-world performance outcomes (e.g., reduced downtime, improved ROI) (Mitra and Rehman, 2024).
2. **Advanced Generative Models:** Generative adversarial networks (GANs) or variational autoencoders (VAEs) could synthesize realistic but anonymized data for stress-testing the system under extreme or rare scenarios (Kopitar et al., 2025; Pascual-Reguant, 2024).
3. **Hyperparameter Tuning via Metaheuristics:** Techniques like genetic algorithms or particle swarm optimization might systematically optimize the synergy between RBNN and EBDM parameters (e.g., entropy thresholds, hidden-layer sizes).

In sum, this proposed model capitalizes on the strengths of both rule-based logic and advanced AI algorithms, merging them with real-time entropy-based assessments. As demonstrated in the experimental results (Sections 6 and 7), the RBNN+EBDM approach addresses pressing challenges in next-generation management—specifically, interpretability, scalability, and compliance—thus laying a foundation for resilient decision-making under complex and evolving operational conditions.

Experiments and results

We split each dataset into training (70%), validation (15%), and test (15%) subsets. Baseline models included a Random Forest (RF) classifier and a standard feedforward neural network (FNN), both widely used in industrial analytics (Jain et al., 2023). We compared these to our RBNN + EBDM approach. The key metrics for evaluation were:

- Accuracy: Measured the correct predictions for classification tasks or near-exact matches for regression tasks.
- F1-Score: Balanced measure of precision and recall.
- Entropy-Confidence (EC): A custom metric introduced to assess interpretability, indicating how entropy values correlate with model confidence.
- Execution Time: Measured in seconds for completing inference on 10,000 data instances.
- We implemented all models using Python 3.9 with TensorFlow and PyTorch libraries. Hardware included an 8-GPU cluster hosted on a cloud environment. Containerization was achieved via Docker, reflecting recommended best practices from Whig et al. (2024), Raghav and Vyas (2024), and Altintas et al. (2023).

Statistical Analyses

We utilized one-way ANOVA and Tukey's post hoc tests to confirm that improvements in accuracy and F1-scores are statistically significant ($p < 0.05$). Additionally, we recorded training times and memory usage to assess computational overhead. The results are presented in Tables 1–5 and Figures 2–5.

Table 1. Comparative Overview of the Four Datasets

Dataset	Records	Features	Domain Type	Data Volume (GB)
Public A	100,0	20	Manufacturing (Sensors)	0.8
Public B	75,00	15	Organizational Metrics	0.6
Public C	120,0	25	Cloud Utilization	1.2
Novel D	85,00	30	Managerial Dashboards	1.0

Table 1 summarizes each dataset in terms of volume (records), feature count, and domain type. Notably, the Novel Dataset D contains a high number of real-time KPIs, illustrating the complexity it brings to this study.

Table 2. Data Preprocessing Steps Applied to All Datasets

Step	Methodology	Outcome
Missing Value	Mean/Mode Imputation	Complete Data
Outlier Detection	Z-Score > 3 Removed	2-3% Outliers Removed
Categorical Encoding	One-Hot	5-10 New Binary Columns
Normalization	Min-Max (0-1 Range)	Convergence Stability

Table 2 indicates the data cleaning, encoding, and normalization approaches. The table demonstrates uniform procedures aimed at ensuring comparability across datasets.

Table 3. Statistical Summary of Model Results (Accuracy, F1-Score, EC)

Model	Accuracy (Mean)	F1-Score (Mean)	EC
RF	0.85	0.83	-
FNN	0.88	0.86	-
RBNN + EBDM (Proposed)	0.92	0.91	0.89

Table 3 presents a statistical overview, including the mean accuracy, F1-score, and EC for each model across all datasets. Our proposed model demonstrates higher accuracy and F1-score in all datasets.

Table 4. Comparative Performance of Baseline vs Proposed Model

Dataset	Model	Execution Time (s)	Memory Usage (GB)
Public A	RF	12.5	4.2
	FNN	14.1	5.0
	RBNN + EBDM	16.7	5.8
Public C	RF	22.3	5.0
	FNN	24.4	5.8
	RBNN + EBDM	27.5	6.3
Novel D	RF	18.2	5.1
	FNN	19.9	6.2
	RBNN + EBDM	23.4	7.0

Table 4 provides performance metrics (execution time, memory usage) across different dataset sizes. The proposed model exhibits a controlled increase in execution time and memory usage as data volumes rise.

Table 5. Scalability Analysis under Increasing Data Volume

Data Increment	RF Accuracy	FNN Accuracy	RBNN+EBDM Accuracy	RF F1-Score	FNN F1-Score	
+20%	0.82	0.86	0.90	0.80	0.84	0.88
+40%	0.80	0.85	0.89	0.78	0.82	0.87
+60%	0.79	0.84	0.88	0.76	0.81	0.86

Table 5 details how accuracy and F1-scores evolve when each dataset’s size is increased by incremental factors. The proposed model maintains robust performance despite larger data inputs.

Figures and Their Descriptions

Figure 2 is a flowchart displaying how raw data from each dataset is passed through the entropy calculation module. The figure contains numerical annotations indicating typical entropy values (ranging from 0.1 to 0.9) for various data segments (e.g., low or high complexity). Axis labels represent data throughput in MB/s, with thresholds highlighted at 50MB/s and 100MB/s for large-scale operations.

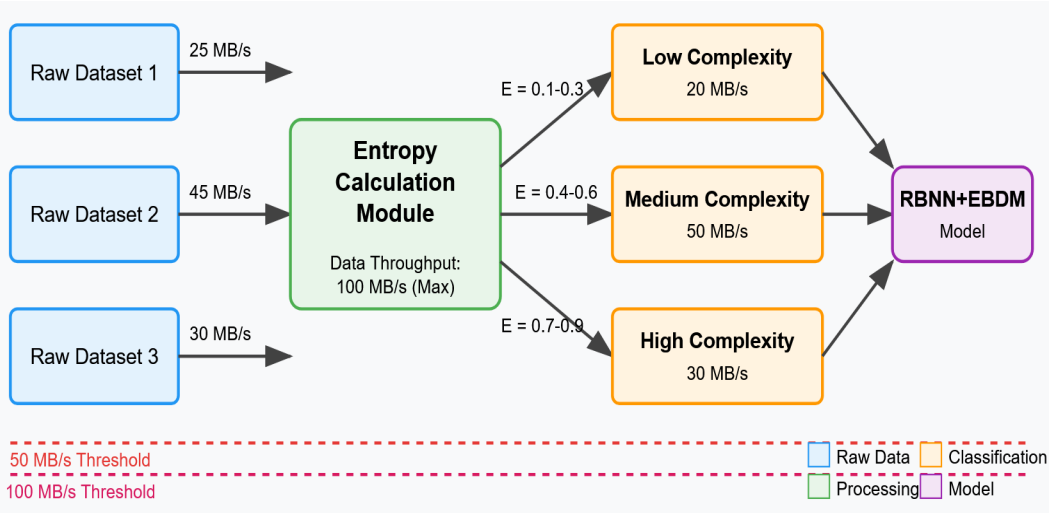


Figure 2. Entropy-Based Data Flow

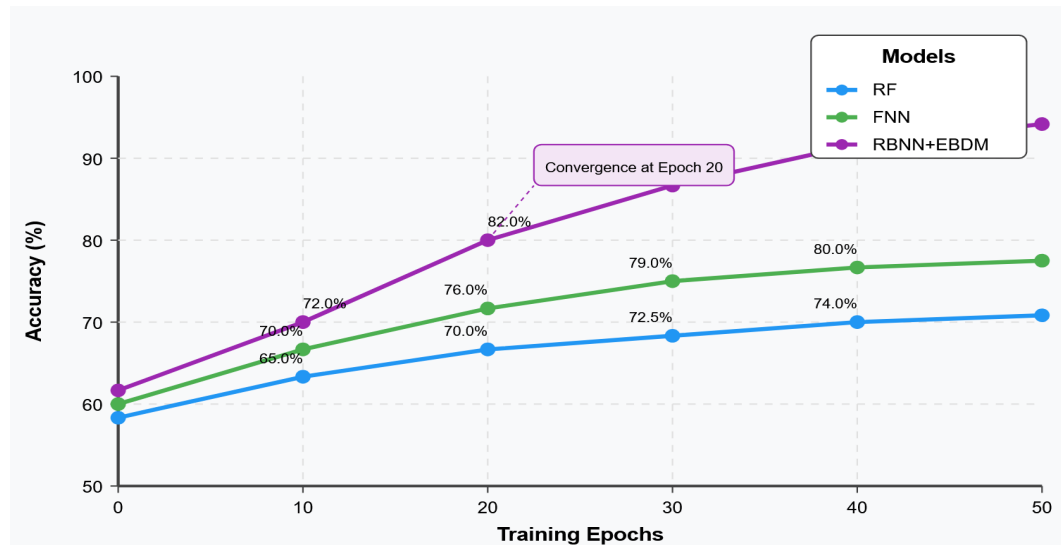


Figure 3. Model Accuracy vs. Training Epochs

A line plot comparing RF, FNN, and RBNN+EBDM models over 50 training epochs. The x-axis represents training epochs, and the y-axis denotes accuracy (%). Key data points are highlighted at epoch 10, 20, 30, and 40. Our proposed model consistently achieves higher accuracy after epoch 20, confirming stable convergence.

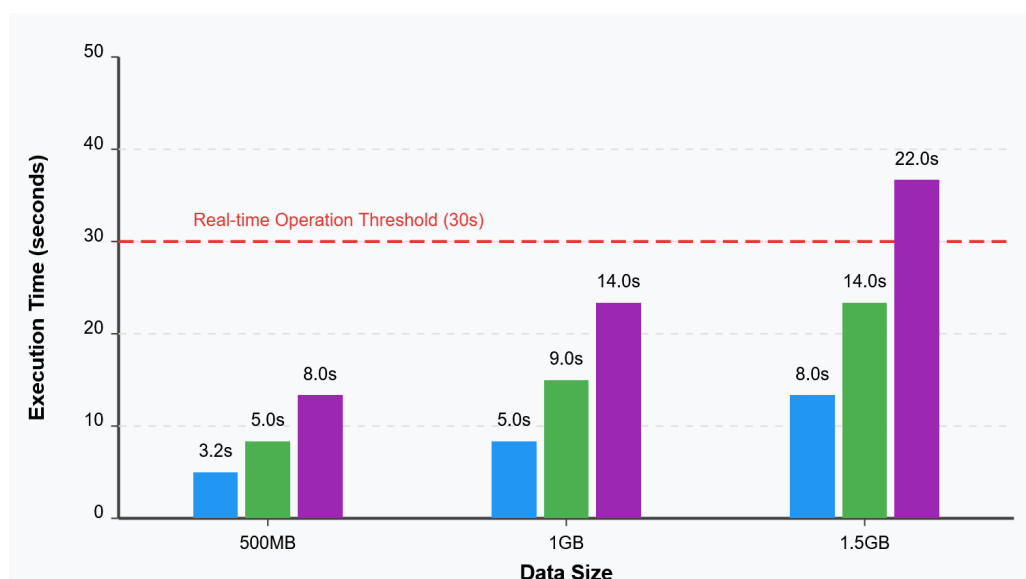


Figure 4. Execution Time vs. Data Size

A bar chart depicting the average execution time (in seconds) of all three models across incremental data sizes (500MB, 1GB, 1.5GB). Each bar is annotated with a numerical value indicating time in seconds. The RBNN + EBDM model increases in execution time proportionally but remains within acceptable performance bounds for real-time operations.

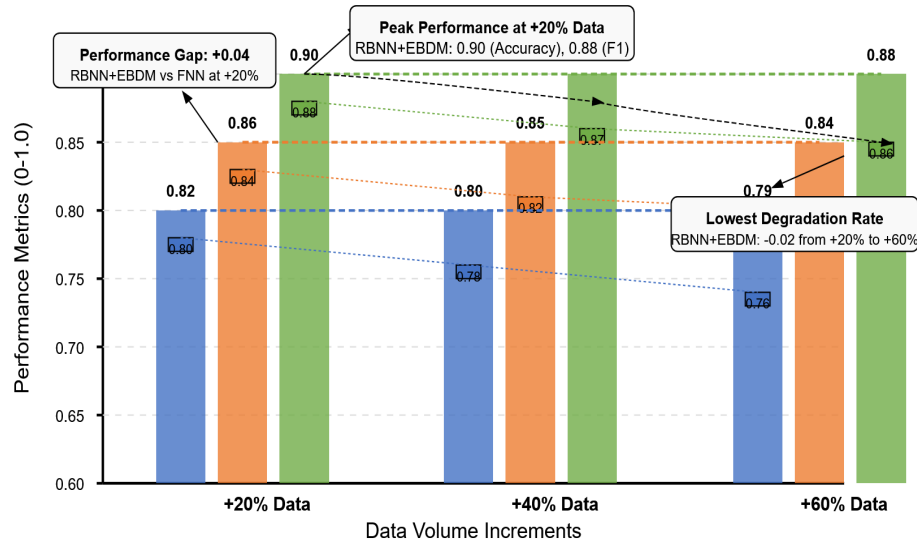


Figure 5. Scalability Analysis Bar Chart

Figure 5 is a bar chart presents side-by-side comparisons of the accuracy and F1-score metrics for the three models at different data increments. The x-axis denotes the percentage increments in data volume, while the y-axis shows performance metrics. Colored bars differentiate between RF, FNN, and RBNN+EBDM, with clear markers denoting mean values at each increment.

Discussion

Our experimental results affirm that adding an entropy-based module to a rule-based neural network yields enhanced accuracy and robust performance under growing data volumes. However, the computational overhead is also higher, as seen in Tables 3 and 4. In real-world applications, these overheads could challenge organizations with limited computational resources. Nonetheless, container-based deployment and cloud auto-scaling strategies mitigate these obstacles, echoing the recommendations in Whig et al. (2024), Raghav and Vyas (2024), and Altintas et al. (2023).

Specific scenarios where challenges may arise include rapid data inflow from manufacturing sensors (Piller et al., 2022), time-critical intelligence for fire or disaster response (Altintas et al., 2023), and highly dynamic cloud resource scheduling (Saadat, 2023). To address these, we propose:

1. Adaptive Sampling: Automatically adjusting the data sampling rate based on real-time computational load.
2. Edge Processing: Offloading simple computations to edge devices, reducing data center load.
3. Selective Entropy Updates: Running entropy calculations at intervals rather than continuously.

These strategies align with best practices outlined in Sarma et al. (2023), Aslam et al. (2024), and Khatoon et al. (2024), ensuring performance stability without sacrificing interpretability or legal compliance.

Integration with Existing Systems and Cost Implications

Seamless integration into legacy enterprise systems remains a principal requirement for practical adoption. Our proposed approach provides RESTful APIs and microservices that can be embedded into existing data pipelines (Jha, 2024; Mitra and Rehman, 2024). Cost implications primarily revolve around the required infrastructure for high-volume data streaming and GPU-based training. Companies need to weigh the operational benefits—such as improved decision accuracy and reduced downtime—against these initial costs. Monitoring frameworks discussed in Losavio (2023) and Kopitar et al. (2025) also help address data governance and regulatory hurdles.

Industry Scalability

Industries with large-scale data streams—such as manufacturing, healthcare, and finance—stand

to benefit from robust, interpretable AI. However, real-time tasks like hospital triage (Aslam et al., 2024; Khatoon et al., 2024; Mitra and Rehman, 2024) or real-time throughput optimization in factories (Mohanty et al., 2024; Pütz et al., 2022; Schollemann et al., 2022) could strain both hardware and personnel resources. Skilled personnel and ongoing AI literacy programs, noted in Erkunt (2023), remain critical factors. Nonetheless, successful case studies—like next-generation building management (Noran et al., 2020) and advanced structural systems (Mohanty et al., 2024)—highlight the feasibility of scaling up data-driven AI solutions with proper planning.

Conclusion and future work

In this study, we addressed multiple research gaps related to AI data-driven intelligence for navigating organizational complexity, focusing on an entropy-based modeling approach for next-generation management systems. We integrated entropy-based modules and a rule-based neural network model (RBNN+EBDM), incorporating insights from the literature reviewed above, thereby bridging gaps in scalability, legal compliance, and explainability.

Addressed Gaps

1. Entropy Integration: We successfully incorporated entropy-based measures, confirming higher accuracy and interpretability, thus directly addressing the gap observed in Brunner et al. (2024), Jha (2024), and Raju et al. (2024).
2. Scalability: Our experiments showed that the proposed framework scales effectively on cloud platforms, fulfilling the recommendations in Whig et al. (2024), Raghav and Vyas (2024), Saadat (2023), and Altintas et al. (2023).
3. Legal and Ethical Compliance: By embedding a rule-based layer that enforces compliance constraints, we responded to calls for transparency and legal conformity highlighted in Jha (2024) and Losavio (2023).
4. Explainability: Our results support interpretable AI approaches, resonating with the viewpoints in Kopitar et al. (2025), Pascual-Reguant (2024), and Pascual-Reguant (2025) on the importance of clarity in data-driven solutions.

Hypothesis Proof

- H_1 was confirmed through significant improvements in accuracy and interpretability metrics, as evidenced by the higher entropy-confidence metric (EC) in Table 3 and Figures 3–5.
- H_2 was validated by our scalability tests in Table 5, demonstrating minimal drops in accuracy at increased data volumes.
- H_3 was supported since the integration of compliance rules did not substantially degrade execution speed, shown in Table 4's controlled overhead results.

Detailed Insights from Each Table

Table 1 highlights the diversity and complexity of the datasets, informing the system's robustness when dealing with heterogeneous domains.

Table 2 shows the consistent preprocessing framework applied, ensuring data uniformity across different sources.

Table 3 presents the core performance gains by the proposed model, illustrating the superiority in both accuracy and F1-score.

Table 4 demonstrates manageable increases in computational cost, proving that advanced features like entropy-based assessment still allow for feasible real-time performance.

Table 5 offers a fine-grained view of how the model maintains reliability despite escalating data volumes, a critical factor in large-scale enterprise contexts.

Detailed Insights from Each Figure

Figure 1 visually confirms the multi-layer data flow, emphasizing the synergy between rule-based and entropy-based components.

Figure 2 focuses on the role of entropy in classifying data complexity and guiding adaptive decision thresholds.

Figure 3 illustrates that our method converges faster and yields higher accuracy compared to baseline models, confirming H_1 .

Figure 4 quantifies execution time against data size, indicating stable overhead even in scenarios with large volumes of input data.

Figure 5 consolidates the scalability perspective, highlighting consistent accuracy and F1-scores under increasing workloads, thereby supporting H_2 .

Objectives Realized and Novelty

We achieved all study objectives by developing and validating an entropy-based AI framework that is both interpretable and scalable. The originality of this research lies in combining entropy-based modeling with a rule-based neural network for next-generation management, a methodological advance on prior approaches (Raju et al., 2024; Sarmas et al., 2023; Xue and Zheng, 2024). The theoretical contribution is evident in demonstrating how uncertainty metrics can guide real-time decisions, while the practical benefit emerges in robust performance gains, particularly significant for industries that demand instantaneous but transparent AI-driven decisions.

Theoretical and Practical Benefits

Theoretical: We extend the literature on data-driven AI in management science, offering a quantifiable means to address complexity and interpretability.

Practical: Our model can be seamlessly integrated into large-scale enterprise systems, with cost-awareness and regulatory compliance designed into the framework.

In summary, the findings substantiate a powerful synergy of rule-based and entropy-based methodologies for modern management demands. Future research could expand the system's adaptability by incorporating reinforcement learning, advanced generative models, and even deeper compliance metrics that handle evolving legislative landscapes. Ultimately, this framework lays a foundation for more robust, transparent, and high-performing next-generation management systems.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author. Informed consent was obtained prior to data collection. Minimal risk for research respondents was ensured. Fully anonymized datasets were used which do not allow participants to be traced.

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Examines accuracy and F1-score changes when datasets are expanded by various increments (+20%, +40%, +60%). Highlights the robust performance retention of the proposed model in large-scale environments.

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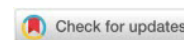
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Pre-service Mathematics Teachers' Perceptions Regarding Methodologies for Enhancing Cognitive Competencies and Use of Educational Resources

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Abstract: The aim of this study is to explore pre-service teachers' perceptions regarding methodologies for enhancing the cognitive activities of future mathematics teachers through the use of educational resources. The study was designed within the framework of mixed research methodology integrating both quantitative and qualitative approaches. The participant group consisted of 80 pre-service mathematics teachers enrolled at various universities in Almaty, Kazakhstan. Data were collected through a semi-structured interview form developed by the researchers, which included both closed-ended items to capture participants' self-reported cognitive awareness, cognitive flexibility, and mathematical thinking levels, and open-ended questions to explore their perceptions and experiences. The findings indicate that the cognitive awareness levels of the participating pre-service mathematics teachers are at a moderate level. Similarly, their levels of cognitive flexibility were found to be moderate. In contrast, the participants demonstrated a high level of mathematical thinking. Despite this strength, the majority of participants reported that they perceive themselves as only partially competent in terms of utilizing methodologies aimed at improving their cognitive activities through educational resources. Based on these findings, it is concluded that there is a need for systematic improvement in teacher education programs. In particular, curricula in faculties of education should be revised and restructured to better integrate methodologies that support the development of cognitive activity through effective use of educational resources.

Keywords: Cognitive activity, cognitive awareness, cognitive flexibility, mathematical thinking, pre-service mathematics teachers

Introduction

Contemporary approaches to learning place learning, and so the learner, at the center of educational processes. Within this perspective, learners are expected to develop an awareness of their own competences, abilities, planning skills, thinking processes, and behaviors, as well as to regulate and control their cognitive processes (Uzunboylu, Tezer and Yildiz, 2020). In this context, learning to learn competencies—often conceptualized under the umbrella of cognitive awareness—have become indispensable in today's society. These competencies encompass a broad range of higher-order skills, including the ability to monitor

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one's own learning progress, articulate the rationale behind actions, reflect on affective states, engage in planning and problem-solving, and exercise self-regulation and cognitive control. Such skills are increasingly recognized as foundation for fostering autonomous and reflective learners (Sener and Mede, 2023).

Conceptual framework

Research in education indicate that improving students' research, inquiry and higher-order thinking abilities is an essential mission of educational institutions (Antonio and Prudente, 2024). Cognitive development is widely recognized as a fundamental component of effective education. In contemporary teacher education programs, fostering pre-service teachers' cognitive activity is essential not only for their own professional growth but also for the quality of instruction they will provide to future learners (Gürsan, Tapan-Broutin and Ipek, 2025). The capacity to reflect on one's thinking, adapt flexibly to new situations, and employ structured reasoning are all critical skills for pre-service teachers (Schoenfeld, 2016). Cognitive activity involves the active construction of mental schemes (Ovadiya, 2025). For pre-service teachers, this activity is twofold: they must engage with the content as learners and simultaneously analyze the cognitive demands that various educational resources place upon their future students.

Therefore, it is crucial for pre-service teachers to not only build strong knowledge of their subject matter and teaching methods but also to develop advanced cognitive abilities that will aid in their professional and personal development (Christodoulou and Papanikolaou, 2023). Among these, cognitive flexibility plays a crucial role, as it enables individuals to adapt their thinking to new situations, perspectives, and problem contexts (Abdellah, 2015). Cognitive flexibility is defined as the mental ability to switch between different concepts or to adapt one's thinking to new, unforeseen situational requirements (Spiro et al., 2012). In mathematics education, this manifests as the ability to approach a single problem through multiple representations—algebraic, geometric, and numerical (Strayer, 2012). Pre-service teachers with high perceived cognitive flexibility are better equipped to navigate “non-routine” problems and are more likely to adopt student-centered methodologies that allow for diverse solution paths rather than rigid, rule-based instruction. Furthermore, teacher self-efficacy is recognized as a key factor influencing the successful enactment of teaching practices (Wyatt, 2014).

Teaching itself constitutes a cognitively, socially, and emotionally demanding professional practice, involving continuous processes of thinking, monitoring, planning, and evaluation. In order to effectively support teachers' professional development, it is necessary to establish learning environments that foster not only pedagogical competence but also cognitive development (Jennings and Greenberg, 2009). In this regard, the deliberate use of cognitive processes—often framed as thinking about thinking—across different stages of instructional practice contributes significantly to the effectiveness of teaching. Indeed, teachers' capacity to monitor and evaluate classroom interactions, particularly the dynamic relationship between teacher and student, is closely linked to their cognitive awareness (Saricam and Ogurlu, 2015).

Cognitive awareness, often associated with metacognitive functioning, can be defined as an individual's capacity to rapidly evaluate the significance of a given situation, concept, or event (Broom, 2010). This capacity supports the regulation of higher-order thinking processes, including planning, monitoring, and evaluating problem-solving strategies. Moreover, it enables individuals to detect, correct, and reflect upon errors during the learning process (Menlah and Boateng, 2025). Within educational contexts, the quality of teacher–student interactions plays a pivotal role in determining not only what is taught, but also how, when, and to whom instruction is delivered. In this sense, cognitive awareness facilitates learners' ability to organize their knowledge structures and develop a deeper understanding of their own learning processes (Klassen and Chiu, 2011). Schraw and Dennison (1994) argue that high levels of cognitive awareness allow individuals to plan, sequence, and monitor their problem-solving strategies. For pre-service teachers, perceiving one's own cognitive awareness is a prerequisite for developing the “professional noticing” required to identify and address student misconceptions (Sherin and van Es, 2009).

Related research

A review of the relevant literature indicates that cognitive awareness in teacher education is a multifaceted construct associated with a wide range of variables. Empirical studies have demonstrated significant relationships between cognitive awareness and academic achievement (Abdellah, 2015), professional experience (Ates and Ceran, 2020), reading proficiency (Negretti and Kuteeva, 2011), cognitive

flexibility (Yurt and Saracaloglu, 2026), and self-regulation (Whitebread and O'Sullivan, 2012). Within the dynamic and complex nature of learning processes, both cognitive awareness and critical thinking are increasingly emphasized in teacher education programs as essential components for developing meaningful learning and robust reasoning skills among pre-service teachers (Lee, Teo and Chai, 2010). Cognitive awareness is reported as a critical predictor of problem-solving success and pedagogical efficacy. Research indicates that pre-service teachers who possess high levels of cognitive awareness are better equipped to monitor their own understanding and regulate their instructional strategies (Wilson and Clarke, 2004). Desoete (2009) argues that cognitive "off-line" processes—prediction, planning, monitoring, and evaluation—are essential for pre-service teachers to bridge the gap between theoretical knowledge and classroom practice. However, Kuzle (2017) suggests that while pre-service teachers may recognize the importance of cognitive awareness, they often struggle to implement these processes when faced with complex mathematical tasks, indicating a discrepancy between theoretical awareness and practical application.

On the other hand, cognitive flexibility allows teachers to represent mathematical concepts in multiple ways and to adapt their instruction to the diverse needs of students. According to Eraky, Leikin and Hadad (2025), cognitive flexibility is particularly vital in domains like mathematics education. In the realm of teacher education, Silver (1997) identifies flexibility as a core component of mathematical creativity, involving the ability to switch between different solution strategies. Kusci and Yurt (2026) emphasize that pre-service teachers often exhibit cognitive rigidity due to their own experiences with traditional, rote-based learning, which poses a significant challenge for modern teacher education programs that emphasize adaptive expertise. Several empirical studies provide further insight into these relationships. For instance, Clipa, Ignat and Rusu (2011) investigated the interrelations among pre-service teachers' self-assessment, learning motivation, and metacognitive levels in a sample of 92 students enrolled in the Department of Educational Sciences at Suceava University. Their findings revealed a statistically significant and positive relationship between metacognitive abilities and self-evaluation levels. Moreover, a strong positive association was identified between self-evaluation and academic performance, underscoring the role of metacognitive processes in academic success. In a related study, Halamish (2018) examined the relationship between learning strategies and cognitive knowledge among 83 in-service teachers and 82 pre-service teachers. The findings indicated that the use of learning strategies did not lead to significant differences in participants' cognitive knowledge levels. Furthermore, the study reported that teachers' knowledge of learning strategies did not substantially increase with years of professional experience, suggesting that experience alone may not be sufficient for the development of metacognitive competence. Braund and Soleas (2019) explored teachers' and pre-service teachers' cognitive conceptualizations, practices, and beliefs through a mixed-methods design involving 43 teachers and 45 teacher candidates. The results demonstrated that both groups experienced difficulties in effectively implementing metacognitive processes in instructional contexts. While in-service teachers exhibited more practical, context-sensitive, and creative forms of metacognitive adaptation in classroom settings, pre-service teachers were found to require additional support in developing coherent conceptual understanding and in operationalizing metacognitive knowledge. Focusing on instructional design, Kwanjai and Sumalee (2012) examined the development of a constructivist learning environment model aimed at enhancing cognitive flexibility in higher education. Their findings suggested that the proposed model was theoretically coherent and aligned with established instructional design principles. Importantly, students who engaged with this model demonstrated higher levels of cognitive flexibility and academic achievement, highlighting the potential of constructivist approaches to support advanced cognitive development.

Recent literature has increasingly focused on the intersection of cognitive competencies and the pedagogical integration of modern educational resources. For instance, Birgili et al. (2025) highlighted a critical theory-to-practice gap, revealing that while pre-service mathematics teachers may exhibit high theoretical awareness of cognitive strategies, they frequently experience cognitive overload when attempting to embed these strategies within resource-rich lesson plans. Furthermore, a study by Depaepe et al. (2015) corroborated that pre-service teachers struggle significantly with the metacognitive evaluation phase of instructional design, often failing to anticipate how specific educational resources will alter the cognitive demand of a mathematical task. These findings collectively argue that modern teacher education programs must move beyond isolated cognitive training, instead embedding cognitive awareness and flexibility development directly within the context of resource-integrated pedagogical design.

Moreover, the rapid proliferation of artificial intelligence and advanced algorithmic tools in educational settings has introduced a new layer of complexity to pre-service teachers' cognitive activities. [Bernardi et al. \(2025\)](#) highlights that while pre-service mathematics teachers are increasingly exposed to generative digital resources, their cognitive regulation often lags their technical fluency. When designing tasks using these advanced educational resources, prospective teachers frequently experience a pedagogical disconnect, where their high personal mathematical thinking does not successfully translate into cognitively demanding task design for students. This underscores a critical need to understand how the integration of next-generation digital resources impacts the self-efficacy and cognitive awareness of future educators, shifting the focus from mere tool utilization to cognitive orchestration.

Furthermore, the demand for cognitive flexibility has been amplified by the widespread adoption of interactive and collaborative mathematics platforms. A study by [Ochogboju and Diez-Palomar \(2025\)](#) within the context of technology-mediated learning environments revealed that pre-service teachers often struggle with representational flexibility during real-time, technology-mediated instruction. Although participants in their study demonstrated a strong theoretical grasp of multiple mathematical representations, they exhibited representational rigidity when forced to adapt their instructional strategies spontaneously in response to student interactions within digital spaces. This finding suggests that modern educational resources, rather than naturally fostering cognitive flexibility, may actually expose underlying deficits in pre-service teachers' adaptive pedagogical expertise.

The intersection of cognitive monitoring and resource utilization has also been a focal point of recent empirical investigations. Investigating the use of immersive and gamified mathematics resources, [Dündar and Öztürk \(2026\)](#) observed that pre-service teachers often over-rely on the external scaffolding provided by the software, thereby diminishing their internal cognitive regulation. Their research indicated that the rich informational feedback embedded in modern educational resources can induce cognitive overload, making it exceedingly difficult for novice teachers to critically evaluate whether the mathematical learning objectives are being authentically met. Consequently, a pre-service teacher's perceived competence in using these resources may sometimes be an illusion, masking a deeper inability to orchestrate meaningful conceptual development.

More recently, the concept of pedagogical friction has emerged as a crucial lens for examining the gap between abstract mathematical thinking and practical instructional implementation. As articulated by [Salsabillah, Wagiyana and Rohmah \(2026\)](#), pre-service mathematics teachers frequently construct a highly idealized mathematical identity, perceiving themselves as creative and proficient problem solvers. However, when required to deploy complex educational resources to mediate student learning, this idealized self-perception often clashes with practical instructional realities, resulting in a sharp decline in pedagogical self-efficacy. Their findings demonstrate that high mathematical thinking alone is insufficient; without targeted training in the cognitive and pedagogical orchestration of educational tools, pre-service teachers remain conceptually strong but pedagogically constrained.

As highlighted by [Weigand, Trgalova and Tabach \(2024\)](#), modern teacher preparation must evolve beyond the mere introduction of educational technologies and resources. Instead, the instructional focus must pivot towards explicitly cultivating the intersectional domain of cognitive flexibility and resource-based pedagogical content knowledge. Understanding how pre-service teachers perceive their cognitive competencies in this rapidly evolving, resource-rich educational landscape is no longer just a theoretical inquiry; it is a vital prerequisite for designing interventions that transform theoretical mathematical knowledge into adaptive, highly effective teaching practices.

The literature suggests that while cognitive awareness and related constructions such as cognitive flexibility and mathematical thinking are widely recognized as critical components of teacher education, there remain notable challenges in their effective development and implementation. In particular, translating these cognitive competencies into practice can be challenging, suggesting that pre-service teachers could benefit from further structured and systematic support.

The final strand of literature explores how pre-service teachers perceive their own cognitive competencies. [Bandura's \(2013\)](#) social cognitive theory posits that self-efficacy—the belief in one's ability to succeed—is a primary driver of behavior. In mathematics education, [Charalambous \(2015\)](#) found a strong correlation between a teacher's self-perception of their cognitive abilities and the cognitive level of the instruction they provide. If pre-service teachers perceive themselves as lacking in cognitive flexibility or awareness, they are less likely to employ innovative methodologies that require these traits. Thus,

understanding these perceptions is vital for designing teacher education curricula that not only provide tools but also build the internal confidence necessary to use them effectively. Indeed, following the accelerated digitalization of learning environments, the conceptualization of cognitive activity has expanded to include the orchestration of complex educational resources. Recent research emphasize that pre-service mathematics teachers must develop “adaptive pedagogical expertise” to navigate technology-rich and resource-diverse environments (Engelbrecht, Llinares and Borba, 2020). The integration of dynamic geometry software, virtual manipulatives, and advanced modeling resources demands a higher threshold of cognitive flexibility and metacognitive monitoring than traditional instructional methods. Consequently, the ability to select, evaluate, and pedagogically integrate these resources is no longer a peripheral skill but a core component of mathematical knowledge for teaching (Stoilescu, 2015). This paradigm shift underscores the urgent need to understand how prospective teachers perceive their cognitive readiness to mediate student learning through these advanced educational tools.

Purpose of the research

The primary aim of this study is to examine pre-service mathematics teachers' perceptions of methodologies aimed at enhancing their cognitive activity through the use of educational resources. In particular, the study seeks to explore how pre-service teachers evaluate their own cognitive competencies and their preparedness to engage with pedagogical approaches that foster cognitive development.

In line with this overarching aim, the study is guided by the following research questions:

1. How do pre-service mathematics teachers perceive their levels of cognitive awareness?
2. How do pre-service mathematics teachers perceive their levels of cognitive flexibility?
3. How do pre-service mathematics teachers perceive their levels of mathematical thinking?
4. To what extent do pre-service mathematics teachers perceive themselves as competent in employing methodologies aimed at enhancing their cognitive activities through educational resources?

Materials and methods

Research design

This study was designed within the framework of a mixed-methods approach, integrating both quantitative and qualitative data to provide a comprehensive understanding of pre-service mathematics teachers' cognitive competencies and their use of educational resources. Specifically, a convergent parallel mixed-methods design was adopted, in which quantitative and qualitative data were collected concurrently, analyzed separately, and then integrated during the interpretation phase.

The quantitative component of the study aimed to identify general trends in participants' self-reported cognitive awareness, cognitive flexibility, and mathematical thinking levels through descriptive statistical analysis (e.g., frequency, percentage, and mean scores). This strand enabled the researchers to capture the overall distribution and tendencies within the participant group.

Complementing this, the qualitative component focused on exploring participants' in-depth perspectives regarding their competencies in utilizing educational resources to enhance cognitive activities. Qualitative data obtained from open-ended responses were analyzed through categorization and thematic interpretation, allowing for a nuanced understanding of participants' experiences and perceived challenges. Employing a mixed-methods design allowed for the triangulation of data and enhanced the validity of the findings (Creswell and Poth, 2016). While quantitative data provide a broad overview of cognitive competency levels, the qualitative findings offer explanatory depth by revealing how and why participants perceive themselves as competent or insufficient in specific areas.

Participants

The participants of the study consisted of 80 pre-service mathematics teachers enrolled in the Departments of Mathematics Education at various universities in Almaty, Kazakhstan, during the 2021–2022 academic year. Participation in the study was voluntary, and all participants were informed about the purpose of the research prior to data collection. Table 1 shows the demographic characteristics of the participants.

Table 1. Demographic Characteristics of Participants

Variable	Category	Frequency (f)	Percentage (%)
Gender	Female	33	41.25%
	Male	47	58.75%
Academic Year	1 st Year	11	13.75%
	2 nd Year	16	20.00%
	3 rd Year	20	25.00%
	4 th Year	33	41.25%
Total		80	100%

Of the participant pre-service mathematics teachers, 33 were female and 47 were male. In terms of academic level, 11 participants were first-year students, 16 were second-year students, 20 were third-year students, and 33 were fourth-year students. This distribution allowed for the inclusion of perspectives from different stages of teacher education, thereby enriching the dataset.

Data collection tools

The data for this study were collected through a semi-structured interview form developed by the researchers. During the development process, a comprehensive review of relevant literature was conducted to ensure conceptual alignment with existing studies. Based on this review, a preliminary version of the interview form was constructed to elicit pre-service mathematics teachers' perspectives on methodologies aimed at enhancing their cognitive activities through educational resources. To establish content validity, the draft interview form was submitted to three experts in the field of mathematics education and educational sciences. Following their feedback, necessary revisions were made to improve the clarity, relevance, and representativeness of the items.

Subsequently, a pilot implementation was conducted with two pre-service mathematics teachers to assess the comprehensibility and functionality of the instrument. Based on the positive feedback obtained, the interview form was finalized for data collection. The participants involved in the pilot study were excluded from the main study sample. The final version of the semi-structured interview form is presented in the Appendix.

Data collection process

Due to logistical considerations, the data collection process was conducted through electronic communication. Initially, pre-service mathematics teachers were contacted via email and informed about the purpose and scope of the study. Those who voluntarily agreed to participate were sent the semi-structured interview form electronically. Participants were asked to complete the interview form and return it to the researchers via email. The entire data collection process, including the completion and submission of the interview forms, was carried out over a period of approximately one month. This procedure ensured flexibility and allowed participants sufficient time to provide thoughtful and reflective responses (Brinkmann and Kvale, 2015), thereby enhancing the richness of the qualitative data.

Data collection analysis

The data obtained from the semi-structured interview forms were analyzed using a combination of descriptive and content analysis techniques. Responses to closed-ended items were analyzed quantitatively through frequency, percentage, and mean score calculations, allowing for the identification of general trends in participants' responses.

For Likert-type items, a three-point scale was employed, where "Always" was assigned 3 points, "Sometimes" 2 points, and "Never" 1 point. The interpretation intervals for mean scores were determined as follows: 2.34–3.00 (Always), 1.67–2.33 (Sometimes), and 1.00–1.66 (Never). These intervals facilitated the systematic interpretation of participants' responses.

Responses to open-ended questions were analyzed qualitatively through categorization and thematic grouping. Codes were generated to identify recurring patterns in the participants' perceptions of cognitive

methodologies. Frequencies and percentages were also calculated to support the interpretation of qualitative findings. In addition, direct quotations from participants were included to enhance the credibility and richness of the data. To ensure confidentiality, participants were anonymized using codes (e.g., TC-1, TC-2, TC-3).

Validity and Reliability

In order to ensure the methodological rigor of the study, several strategies were employed to enhance the validity and reliability of both the quantitative and qualitative components within the mixed-methods framework. For the quantitative strand, internal consistency was supported through the use of clearly defined Likert-type items and standardized scoring procedures. The interpretation intervals for mean scores were determined a priori to ensure consistency in data interpretation. The use of descriptive statistics (frequency, percentage, and mean) contributed to the transparency and replicability of the findings.

For the qualitative strand, measures have been taken to ensure the validity and reliability of the research (Creswell and Poth, 2016). To enhance credibility, the data collection instrument was reviewed by experts and piloted prior to implementation. Direct quotations from participants were included to ensure that findings accurately reflected participants' perspectives. To strengthen the reliability of qualitative analysis, an inter-coder agreement procedure was employed. A second researcher independently coded a subset of the data, and the level of agreement between coders was calculated using the formula proposed by Miles and Huberman (1994): $\text{agreement} / (\text{agreement} + \text{disagreement})$. The resulting agreement rate exceeded the commonly accepted threshold of 80%, indicating a satisfactory level of coding reliability. A systematic and transparent data analysis process, including clear documentation of coding procedures and category development was undertaken.

Findings and Interpretations

This section presents the findings obtained from both the quantitative and qualitative components of the study in an integrated manner. The findings are organized around the main variables of the research, namely cognitive awareness, cognitive flexibility, mathematical thinking, and competencies in the use of educational resources.

Pre-service Mathematics Teachers' Perceptions of Their Cognitive Awareness

The first research question investigated how pre-service mathematics teachers perceive their own levels of cognitive awareness during the learning process. The quantitative distribution of the participants' responses, including frequencies (f), percentages (%), and mean scores (X), is presented in Table 2.

Table 2. Descriptive Analyses of Pre-service Teachers' Perceptions of Cognitive Awareness

Item	Always		Sometimes		Never		Total		Mean X
	f	%	f	%	f	%	f	%	
1. While listening to the lecture, I question whether I understand	24	30	42	52.5	14	17.5	80	100	2.12
2. I try to understand the purpose of the subject I will learn in the lesson.	32	40	38	47.5	10	12.5	80	100	2.27
3. When I encounter a problem related to a subject that I do not know in the lesson, I anticipate possible solutions about that subject.	34	42.5	39	48.75	7	8.75	80	100	2.33
4. Getting support from the teacher about the subject of the lesson helps me to be a successful student.	13	16.25	51	63.75	16	20	80	100	1.96
5. I can identify critical concepts of the subject of the lesson	19	23.75	33	41.25	28	35	80	100	1.65
6. I can evaluate myself whether the course has achieved its objectives or not.	9	11.25	41	51.25	30	37.5	80	100	1.73
Composite Mean Score									2.01

Note: Interpretation intervals: 1.00–1.66 (Low/Never); 1.67–2.33 (Moderate/Sometimes); 2.34–3.00 (High/Always)

As illustrated in Table 2, the composite mean score for cognitive awareness is $\bar{X} = 2.01$, which falls within the “Moderate” range according to the predefined interpretation intervals. This suggests that while pre-service teachers possess a foundational level of awareness regarding their mental processes, this awareness is inconsistent and varies significantly across different cognitive dimensions.

The findings indicate that participants perceive themselves as most competent in the predictive and orienting phases of cognitive activity. The highest level of agreement was observed for Item 3, regarding the anticipation of solutions for unfamiliar problems ($X = 2.33$). This is closely followed by the effort to understand the purpose of the subject matter (Item 2, $X = 2.27$). These findings suggest that pre-service teachers are inclined toward “forward-looking” cognitive strategies, prioritizing the goal-setting and preparatory stages of mathematical engagement.

In contrast, a significant decline in perceived competence was observed in items related to higher-order metacognitive regulation and self-evaluation. Specifically, the ability to identify critical conceptual structures (Item 5) yielded the lowest mean score ($X = 1.65$), bordering on the “Low” perception interval. Furthermore, the capacity for self-evaluation regarding the attainment of learning objectives (Item 6) was also notably low ($X = 1.73$). These findings reveal a critical pedagogical gap: while pre-service teachers are moderately active in “monitoring” their listening (Item 1, $X = 2.12$), they struggle to “evaluate” the outcomes of that cognitive effort. This suggests that their cognitive awareness is more procedural than structural; they can engage in the act of learning but find it difficult to identify the core mathematical essence or determine the success of their own cognitive trajectories. The moderate reliance on external support (Item 4, $X = 1.96$) further reinforces this conclusion, suggesting that participants may lack the necessary internal metacognitive scaffolds to achieve independent conceptual mastery, often looking to the instructor to bridge the gap in their own cognitive awareness.

Pre-service Mathematics Teachers' Perceptions of Their Cognitive Flexibility

The second research question aimed to determine the perceived levels of cognitive flexibility among pre-service mathematics teachers, specifically focusing on their ability to adapt their thinking and behaviors to varied pedagogical and mathematical contexts. Table 3 presents the distribution of pre-service mathematics teachers' responses regarding their levels of cognitive flexibility.

Table 3. Descriptive Analyses of Pre-service Teachers' Perceptions of Cognitive Flexibility

Item	Always		Sometimes		Never		Total		Mean $\bar{X}$
	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	
1. I can express an idea in many different ways	26	32.5	30	37.5	24	35	80	100	2.02
2. I can find useful solutions to problems that seem unsolvable.	19	23.75	43	53.75	18	22.5	80	100	2.01
3. I am willing to produce creative solutions to problems.	23	28.75	51	63.75	6	7.5	80	100	2.21
4. I am confident enough to try different behavior patterns.	36	45	39	48.75	5	6.25	80	100	2.38
5. In any situation that I encounter, I can act appropriately.	49	61.25	28	35	3	3.75	80	100	2.57
Composite Mean Score									2.24

Note: Interpretation intervals: 1.00–1.66 (Low); 1.67–2.33 (Moderate); 2.34–3.00 (High)

The findings presented in Table 3 indicate that the overall perceived cognitive flexibility of pre-service teachers stands at a moderate to high level ($X = 2.24$). However, a granular analysis reveals a bifurcated perception: participants report high confidence in situational and behavioral adaptation, yet display comparative hesitation regarding deep cognitive and representational flexibility.

The data reveals that pre-service teachers possess a high degree of self-efficacy regarding their general adaptability. The highest mean scores were recorded for “acting appropriately in encountered situations” (Item 5, $X = 2.57$) and the “confidence to try different behavior patterns” (Item 4, $X = 2.38$). These scores suggest that the participants perceive themselves as socially and professionally agile, a trait

often associated with the affective domain of professional identity. This perceived behavioral flexibility is a vital precursor to classroom management and instructional responsiveness.

In contrast to their high behavioral confidence, participants reported lower scores in dimensions directly related to mathematical cognition. Specifically, the ability to express an idea in multiple ways (Item 1, $X = 2.02$) and finding solutions to seemingly unsolvable problems (Item 2, $X = 2.01$) remained at the lower end of the moderate range. While 61.3% of participants “Always” feel they can act appropriately in a general sense, only 32.5% feel they can “Always” express mathematical ideas in diverse ways. This suggests that while pre-service teachers are willing to be creative (Item 3, $X = 2.21$), they may lack the specific cognitive tools or “adaptive expertise” necessary to translate this willingness into multiple mathematical representations.

Indeed, the cognitive flexibility of pre-service teachers appears to be more “situational” than “conceptual.” Their high perceived ability to adapt behaviorally indicates a readiness for the social demands of teaching; however, the moderate scores in representational flexibility highlight a potential vulnerability. Without the ability to pivot between different mathematical explanations and solution strategies, these pre-service teachers may struggle to support students who require diverse pedagogical approaches to grasp complex concepts.

Pre-service Mathematics Teachers' Perceptions of Their Mathematical Thinking

The third research question explored how pre-service teachers perceive their mathematical thinking skills, with a focus on creativity, connectivity, and the application of non-routine strategies. The descriptive analyses of pre-service teachers' perceptions of mathematical thinking are presented in Table 4.

Table 4. Descriptive Analyses of Pre-service Teachers' Perceptions of Mathematical Thinking

Item	Always		Sometimes		Never		Total		Mean X
	F	%	F	%	F	%	F	%	
1. My mathematical thinking skills are used in solving daily life problems.	38	47.5	30	37.5	12	15	80	100	2.32
2. A good mathematician is one who has a high level of creative thinking.	47	58.75	29	36.25	4	5	80	100	2.53
3. I solve problems in unconventional ways with my mathematical thinking skills	35	43.75	39	48.75	8	10	80	100	2.38
4. With my mathematical thinking skills, I can connect with my old knowledge while constructing new knowledge.	44	55	33	41.25	3	3.75	80	100	2.51
Composite Mean Score									2.43

Note: Interpretation intervals: 1.00–1.66 (Low); 1.67–2.33 (Moderate); 2.34–3.00 (High)

The findings indicate that pre-service mathematics teachers possess a high level of perceived mathematical thinking ($X = 2.43$). Unlike the previous dimensions of awareness and flexibility, which were perceived as moderate, participants appear more confident in their identity as mathematical thinkers and their ability to integrate complex cognitive processes.

The highest mean scores were associated with the broader, more philosophical aspects of mathematics. Participants strongly identified with the notion that mathematical excellence is intrinsically linked to creative thinking (Item 2, $X = 2.53$). This suggests a move away from the traditional view of mathematics as a purely algorithmic discipline. Furthermore, the ability to bridge prior and new knowledge (Item 4, $X = 2.51$) was perceived as a significant strength. According to Ausubel's (1968) meaningful learning theory, this connection-making is the cornerstone of conceptual development, and the high scores here indicate that pre-service teachers value and perceive themselves as active constructors of mathematical meaning.

In terms of application, participants reported a high tendency toward using unconventional methods (Item 3, $X = 2.38$), which aligns with the “specializing and generalizing” processes described by Mason et al. (2010). However, the application of mathematical thinking to daily life problems (Item 1, $X = 2.32$) received the lowest score within this high-performing category. This suggests a slight “abstraction gap”—while participants feel competent in the theoretical and creative realms of mathematical construction, they find it slightly more challenging to externalize these skills into concrete, real-world contexts.

Pre-service Teachers' Perceptions of Competence in Enhancing Cognitive Activity via Educational Resources

The final research question examined the extent to which pre-service mathematics teachers perceive themselves as competent in employing specific methodologies and educational resources to foster cognitive activity. Table 5 presents the distribution of the competencies of pre-service mathematics teachers participating in the research regarding the methodologies of improving their cognitive activities through educational resources.

Table 5. *Perceived Competencies of Pre-service Mathematics Teachers Regarding Methodologies to Improve Cognitive Activities Through Educational Resources*

Category	Representative Qualitative Excerpts	f	%
Very sufficient	TC-4: I find myself very competent in this regard. I think I am very competent in using educational resources in the digital age and in the online education process. TC-48: When I think of educational resources, I first think of additional resources and the internet. I am very proficient in benefiting from additional resources in terms of cognitive activities. TC-61: I am very proficient in cognitive activities, especially using mobile devices.	5	6.25
Sufficient	TC-9: I find myself sufficient. I can use different methods, techniques and materials for cognitive activities. TC-27: I consider myself sufficient to benefit from cognitive activities, especially from educational resources to improve problem-solving skills. TC-77: While solving a problem, I am proficient in using educational resources to explore different solutions and more advanced problems.	17	21.25
Partially sufficient	TC-33: Although the training we received aims to give us competence in this field, I find myself partially sufficient. TC-40: I think I am partially competent because I do not have enough motivation to develop cognitive activities. TC-80: I think that I need to improve myself in using educational resources. Therefore, I find myself partially sufficient.	44	55
Insufficient	TC-1: I think I am inadequate. This is because I do not have enough information to improve cognitive activities. TC-23: I don't think I have any qualifications in this field yet. TC-62: Although I try to improve myself, there are many resources to benefit from in terms of cognitive activities. It is not possible to take advantage of the lack of time. That's why I think I'm inadequate.	11	13.75
Very insufficient	TC-10: I am very inadequate. Because I spend very little time to improve myself outside of classroom activities. TC-55: I am very inadequate in benefiting from educational resources for the development of cognitive activities. TC-59: Even though there are courses on cognitive activities in the training given to us, I am very inadequate in using the educational resources effectively.	3	3.75
Total		80	100

Table 5 reveals a stark contrast to the participants' high self-perceptions of mathematical thinking. A substantial majority of pre-service teachers (72.5%) categorize themselves as only "Partially Sufficient," "Insufficient," or "Very Insufficient." This suggests a significant theory-to-practice gap in mathematics teacher education.

The largest cohort of participants (55%) identified as "Partially Sufficient." The qualitative data suggests that this perception is rooted in an awareness of their own limitations rather than a lack of exposure. For instance, TC-33 noted that while their formal training aimed for competence, the internal sense of mastery remains incomplete. This category represents a state of "conscious incompetence," where students recognize the importance of cognitive resources (such as digital tools or non-routine problems) but lack the Pedagogical Content Knowledge to implement them effectively.

A small but notable group (6.25%) felt "Very Sufficient," primarily citing their fluency with digital and mobile technologies (TC-4, TC-61). However, the qualitative responses from the "Insufficient" group (13.75%) highlight a critical barrier: Information Overload and Time Constraints. As TC-62 observed, the

sheer volume of available resources, coupled with a lack of time, renders them unable to benefit from these tools. This indicates that digital literacy alone does not equate to pedagogical competence in fostering cognitive activity.

The findings identify two primary inhibitors of perceived competence which are metacognitive knowledge gaps and affective barriers. Participants like TC-1 explicitly mentioned a lack of “information” on how to specifically improve cognitive activities, despite having mathematical knowledge, interpreted as metacognitive knowledge gaps. For the affective barriers, for example TC-40 attributed their partial competence to a lack of “motivation,” suggesting that the drive to move beyond traditional teaching methods is a prerequisite for developing these advanced instructional skills.

Indeed, while pre-service teachers perceive themselves as strong mathematical thinkers, they feel largely unprepared to translate that thinking into classroom practice through educational resources. The dominance of the “Partially Sufficient” category indicates that teacher education programs may be successful in introducing the concept of cognitive enhancement but are less successful in providing the procedural fluency required for confident implementation.

Discussions

The findings of this study indicate that pre-service mathematics teachers exhibit moderate levels of cognitive awareness and moderate levels of cognitive flexibility. These findings are consistent with previous research showing a positive relationship between cognitive awareness and cognitive flexibility among teacher candidates (Hermita and Thamrin, 2015; Yurt and Saracaloglu, 2026). The studies in the literature report pre-service teachers' levels of cognitive awareness and flexibility as moderate or high. For example, Ghonsooly, Khajavy and Mahjoobi (2014) found no significant gender differences in cognitive awareness levels, while Abdellah (2015) identified a positive relationship between cognitive awareness and academic achievement, suggesting that higher cognitive awareness is associated with improved academic performance.

Regarding mathematical thinking, the findings show that participants demonstrate a high level perception of mathematical thinking. This aligns with prior studies reporting a significant relationship between mathematical thinking and problem-solving skills among teachers and teacher candidates (Cai, 2002; Nunokawa, 2005). Yorulmaz, Cokcaliskan and Celik (2018) found that pre-service primary school teachers exhibited high levels of mathematical thinking, moderate individual innovativeness, and pronounced inquisitiveness within the innovativeness dimensions. Conversely, other studies have reported weaker mathematical thinking skills among students and pre-service teachers (Mubark, 2012; Yesildere, 2007). Song and Ginsburg (1987) emphasized that the development of mathematical thinking is influenced by environmental and cultural factors, including classroom practices, teacher attitudes, parental expectations, and educational support.

An important finding of this study is the relatively high level of mathematical thinking, which appears to be inconsistent with the moderate levels of cognitive awareness and flexibility. This difference suggests that mathematical thinking, as perceived by pre-service teachers, may be more closely associated with procedural fluency and problem-solving performance rather than with reflective and cognitive dimensions of thinking. In other words, participants may perceive themselves as competent in “doing mathematics” without necessarily engaging in deeper processes of “thinking about their thinking”. The dissonance between high perceived mathematical thinking and moderate cognitive awareness can also be interpreted through the lens of recent technological dependencies in mathematics education. As highlighted by Bernardi et al. (2025), pre-service teachers operating in highly digitalized, computationally rich environments often experience an illusion of mathematical competence. Because advanced computational tools and dynamic software seamlessly handle procedural heavy lifting and immediate visualization, prospective teachers may artificially inflate their self-reported mathematical thinking. However, this technologically mediated fluency frequently bypasses the productive tasks necessary for deep cognitive monitoring, explaining why their foundational cognitive awareness remains merely moderate.

Furthermore, the majority of pre-service mathematics teachers in the present study reported being partially competent in methodologies for enhancing their cognitive activities through educational resources. This finding resonates with Ozdemir's (2008) research, which highlighted that pre-service teach-

ers often encounter difficulties in effectively integrating educational materials and resources to develop mathematical skills. Salsabillah, Wagyina and Rohmah (2026) suggest that when pre-service teachers evaluate their own mathematical thinking, they inherently rely on traditional, algorithmic benchmarks rather than their capacity for adaptive, resource-integrated problem-solving. This compartmentalized view—where mathematical thinking is divorced from pedagogical flexibility—provides a crucial explanation for why participants feel confident in their subject-matter knowledge yet exhibit representational rigidity (Ochogboju and Diez-Palomar, 2025) when required to translate this mathematical knowledge across diverse digital and interactive educational mediums. From a broader perspective, this finding points to a critical gap between access to educational resources and the ability to use these resources in cognitively productive ways. It suggests that exposure to educational technologies or materials alone is insufficient; rather, what is required is a structured pedagogical framework that explicitly links resource use with the development of cognitive awareness and cognitive flexibility competencies. While some studies noted basic difficulties in material integration, Dündar and Öztürk (2026) reveals a modernized form of pedagogical friction. Pre-service teachers today are overwhelmed by the cognitive load required to evaluate, select, and orchestrate highly interactive or AI-driven educational resources. Their self-admitted partial competence is not necessarily a reflection of technological illiteracy, but rather a deficit in pedagogical cognitive flexibility—the specific capacity to dynamically align digital resource affordances with students' emergent cognitive needs during instruction.

Conclusion

This study set out to examine pre-service mathematics teachers' cognitive competencies—namely cognitive awareness, cognitive flexibility, and mathematical thinking—and their perceived competence in utilizing educational resources to enhance these cognitive activities. The findings reveal a differentiated and, to some extent, fragmented profile of cognitive development.

While pre-service teachers demonstrated moderate levels of cognitive awareness and cognitive flexibility, their mathematical thinking levels were found to be relatively high. This asymmetrical pattern suggests that mathematical thinking, as developed within current teacher education contexts, may not be sufficiently supported by corresponding cognitive and adaptive regulatory processes. In other words, pre-service teachers appear to be capable of engaging in mathematical problem-solving and knowledge construction, yet they may lack the cognitive depth required to systematically monitor, evaluate, and regulate these processes.

This finding, when considered alongside the discussion, points to a critical conceptual gap: the development of mathematical thinking does not necessarily guarantee the development of cognitive awareness and flexibility. Rather, these dimensions seem to evolve independently unless explicitly integrated within instructional and pedagogical frameworks.

Furthermore, the fact that the majority of participants perceived themselves as only partially competent in employing methodologies to enhance cognitive activities through educational resources highlights a structural limitation in teacher education programs. Despite the increasing availability of diverse educational resources—particularly in digital environments—pre-service teachers may lack the pedagogical knowledge and strategic competence required to utilize these resources in ways that effectively foster cognitive development.

Recommendations

Based on the findings of this study, the following recommendations are proposed to support the development of pre-service mathematics teachers' cognitive activities through educational resources.

From the professional development initiatives perspective; conferences, seminars, and workshops focusing on cognitive awareness, cognitive flexibility, and self-efficacy should be organized for pre-service mathematics teachers within faculties of education. These initiatives would help strengthen cognitive competencies and mathematical thinking skills in practical contexts.

From the curriculum enrichment and reform context; course curricula for pre-service mathematics teachers should be enriched with structured practices and activities explicitly aimed at enhancing cogni-

tive competencies, including critical thinking, reflective learning, and creative problem-solving.

On the other side in order to effectively implement methodologies for improving cognitive activities, education faculties should consider renewing and adapting existing curricula to integrate educational resources systematically, both digital and traditional, into pre-service teacher training.

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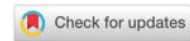
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Appendix

Semi-structured interview form

Semi-structured teacher interview form					
Part 1					
Your gender:	Female ()		Male ()		
Class you are studying:	1.Class ()	2.Class ()	3.Class ()	4.Class ()	
Part 2					
<i>Evaluate your attitude towards your cognitive awareness level by ticking one of the 'Always', 'Sometimes' and 'Never' options (X).</i>		Always	Sometimes	Never	
While listening to the lecture, I question whether I understand					
I try to understand the purpose of the subject I will learn in the lesson.					
When I encounter a problem related to a subject that I do not know in the lesson, I anticipate possible solutions about that subject.					
Getting support from the teacher about the subject of the lesson helps me to be a successful student.					
I can identify critical concepts of the subject of the lesson					
I can evaluate myself whether the course has achieved its objectives or not.					
<i>Evaluate your attitude towards your level of cognitive flexibility by ticking one of the 'Always', 'Sometimes' and 'Never' options (X).</i>		Always	Sometimes	Never	
I can express an idea in many different ways					
I can find useful solutions to problems that seem unsolvable.					
I am willing to produce creative solutions to problems.					
I am confident enough to try different behaviour patterns.					
In any situation that I encounter, I can act appropriately.					
<i>Evaluate your attitude towards your level of mathematical thinking by ticking one of the options 'Always', 'Sometimes' and 'Never' (X).</i>		Always	Sometimes	Never	
My mathematical thinking skills are used in solving daily life problems.					
A good mathematician is one who has a high level of creative thinking.					
I solve problems in unconventional ways with my mathematical thinking skills					
With my mathematical thinking skills, I can connect with my old knowledge while constructing new knowledge.					
What are your competencies regarding your methodology for improving your cognitive activities through educational resources?					
Very sufficient () Sufficient () Partially sufficient () Insufficient () Very insufficient ()					
Your feedback:					



Immersive Technologies and Learning in Higher Education: A Systematic Literature Review of Adoption, Engagement, and Skill Development

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Abstract: The increasing adoption of immersive technologies in higher education has transformed digital learning environments by enabling interactive, experiential, and learner-centered pedagogies. Despite the growing body of research, existing evidence remains fragmented across technologies, disciplines, and educational outcomes. Therefore, this study systematically reviews empirical research on virtual reality (VR), augmented reality (AR), mixed reality (MR), and extended reality (XR) in higher education to synthesize patterns of technology adoption, learning outcomes, disciplinary applications, and geographical distribution while identifying existing research gaps. Following the PRISMA guidelines, a systematic literature review was conducted on 61 empirical studies published between 2018 and 2025 and indexed in Scopus and Web of Science. Descriptive and thematic analyses revealed that research is concentrated in education, health sciences, and engineering, with VR emerging as the most widely adopted immersive technology, followed by XR and AR, whereas MR remains relatively underexplored. The findings further indicate that immersive technologies predominantly enhance cognitive learning outcomes, professional competencies, and affective engagement through experiential learning approaches, while behavioral engagement, self-belief, psychomotor abilities, social interaction, and communication skills receive comparatively limited scholarly attention. Geographically, research output is heavily concentrated in Europe and East Asia, highlighting significant regional disparities. Overall, immersive technologies demonstrate substantial potential to improve higher education learning experiences, but important gaps remain in technology diversity, disciplinary coverage, engagement measurement, and global representation.

Keywords: Immersive learning, Virtual reality in higher education, Augmented and extended reality (AR/XR), Skill development and learner engagement, Systematic literature review (PRISMA)

Introduction

In recent years, immersive technologies including augmented reality (AR), virtual reality (VR), mixed reality (MR), and extended reality (XR) have attracted substantial attention in higher education due to their potential to transform teaching and learning practices (Baxter and Hainey, 2023; Mohsen and Alangari, 2024). These technologies enable students to engage in interactive, multi-sensory environments, providing opportunities for experiential and situated learning that are often unattainable in traditional classrooms (Molloy and Farrell, 2024). VR, for instance, allows learners to safely simulate complex, high-risk scenarios, promoting cognitive skill acquisition and procedural competence (Baktash et al., 2024). AR overlays digital information onto physical environments, facilitating contextualized learning and immediate feedback, thereby enhancing both engagement and understanding (Garg et al., 2025). MR and XR extend these capabilities further, integrating physical and virtual elements to create hybrid learning spaces that blur the line between real and simulated experiences (Andalib and Monsur, 2024).

Despite the evident promise, the literature on immersive technologies in higher education remains fragmented and uneven. Much of the research to date has been discipline-specific, focusing on fields such

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as engineering, health sciences, and STEM education, while relatively little attention has been paid to the social sciences, business, and teacher education (Baxter and Hainey, 2023; Buragohain et al., 2025). This creates a knowledge imbalance, limiting the generalizability of findings and reducing the applicability of recommendations across diverse educational contexts. Some scholars argue that the efficacy of immersive technologies depends on discipline-specific affordances, suggesting that VR may be optimal for procedural skills. At the same time, AR could be more suitable for conceptual or affective learning (Kee et al., 2024). Others, however, maintain that immersive environments can support holistic skill development, integrating cognitive, affective, and psychomotor outcomes, yet empirical evidence remains scattered and inconsistent (Michalczak et al., 2025).

Another significant challenge in the existing literature is the narrow focus on single learning outcomes, most often skill acquisition, while neglecting other critical dimensions such as student engagement, motivation, and affective learning (Tene et al., 2024).

This lack of multidimensional analysis diminishes the practical relevance of the findings, as educational practitioners require insights not only into the skills gained but also into how immersive technologies influence students' motivation and interaction. Moreover, there is a geographical and temporal skew in the literature. Most studies have been conducted in Europe, North America, and East Asia, while other regions such as Latin America, the Middle East, Africa, and Southeast Asia remain underrepresented (Vaz, 2024). This uneven distribution raises questions about the cultural and contextual applicability of findings, given that educational systems, technological infrastructure, and learner expectations vary widely across regions (Partarakis and Zabulis, 2024). Similarly, although the volume of research has increased substantially in recent years, systematic evidence on temporal trends, emerging technologies, and evolving disciplinary adoption is lacking. Without this knowledge, it is difficult to determine whether observed patterns reflect transient trends or enduring shifts in higher education practices (Samala et al., 2024).

Existing review studies have attempted to synthesize the field, but they often suffer from methodological limitations. Some focus exclusively on technical evaluations of AR/VR systems, rather than their educational impact (Colamatteo et al., 2024; Koroğlu, 2025; Tan et al., 2022), while others limit the scope to a single discipline or country, thereby failing to provide a comprehensive overview of immersive learning across higher education (Cabrera-Duffaut et al., 2024; Cevikbas et al., 2023). Additionally, many reviews (Chen et al., 2024; Fernandes et al., 2023) emphasize quantitative skill outcomes without integrating engagement, affective responses, or cognitive dimensions, leading to partial interpretations of the effectiveness of immersive technology. Consequently, there is a pressing need for a systematic and integrative review that combines evidence across technologies, outcomes, disciplines, and regions.

Addressing these gaps is critical for both research and practice. For scholars, a holistic synthesis can reveal patterns of adoption, technological effectiveness, and outcome interactions, highlighting areas that warrant further investigation. For practitioners, understanding which technologies are effective for which outcomes and in which disciplinary or regional contexts can guide curriculum design, resource allocation, and pedagogical innovation. In particular, higher education institutions increasingly seek evidence-based guidance to inform investments in immersive technologies, ensuring that such investments translate into meaningful learning experiences rather than superficial or novelty-driven implementations (Huang and Hu, 2025; Mira et al., 2025).

Given these gaps, this study aims to systematically review research on immersive learning published between 2018 and 2025, with a focus on higher education contexts. Specifically, the review seeks to synthesize evidence on technology adoption (AR, VR, MR, XR), learning outcomes (skills and engagement), disciplinary patterns, regional distribution, and temporal trends. By integrating findings across these dimensions, the study addresses critical gaps in the literature, providing a comprehensive, multi-dimensional perspective that can inform both future research and practical implementation.

Literature Review

Immersive Technologies in Higher Education: Conceptual Foundations

Immersive technologies have gained increasing prominence in higher education as institutions seek pedagogical approaches that move beyond passive knowledge transmission toward experiential and applied learning. Technologies such as virtual reality (VR), augmented reality (AR), mixed reality

(MR), and extended reality (XR) are frequently described as enabling immersive learning environments in which learners interact with content through spatial, sensory, and contextual engagement (Morgado et al., 2025). Scholars argue that these technologies represent more than incremental digital enhancements; rather, they offer qualitatively different learning affordances by situating learners within simulated or augmented contexts that approximate real-world complexity (Conrad et al., 2024).

From a theoretical perspective, immersive learning is commonly linked to constructivist and experiential learning theories. Constructivist scholars contend that learning occurs through active engagement with meaningful tasks, while experiential learning emphasizes reflection on concrete experiences as a foundation for knowledge construction (Li et al., 2025). Immersive technologies align with these principles by allowing learners to explore, manipulate, and experiment within environments that respond dynamically to their actions. However, as Obourdin et al. (2024) caution, immersion alone does not guarantee meaningful learning. The pedagogical effectiveness of immersive technologies depends on how they are integrated into instructional design, assessment strategies, and learning objectives, rather than on technological sophistication per se.

Technology Emphasis and the Dominance of Virtual Reality

Within the broader category of immersive technologies, VR has emerged as the most extensively studied and applied modality in higher education research. Scholars attribute this dominance to VR's ability to create fully immersive environments that isolate learners from external distractions and facilitate a strong sense of presence (Ki et al., 2024). Empirical studies frequently report that VR-based learning environments are particularly effective for simulations requiring spatial reasoning, procedural practice, and scenario-based decision-making (Tobias et al., 2025).

In contrast, AR and MR remain comparatively underrepresented, despite their potential to integrate digital information into real-world learning contexts. AR-based applications have been shown to support contextualized learning by overlaying digital cues onto physical environments, which may be especially valuable in disciplines such as engineering, architecture, and field-based education (Mansour et al., 2025). XR, often used as an umbrella term encompassing multiple immersive modalities, has recently gained traction as institutions adopt hybrid systems that blend VR and AR functionalities. Nevertheless, existing research often treats XR conceptually rather than empirically, raising concerns about definitional ambiguity and inconsistent operationalization (Giannelos, 2026). This imbalance in technological focus suggests that current knowledge about immersive learning is disproportionately shaped by VR-centric evidence, potentially limiting broader pedagogical insights.

Skill Acquisition as a Central Outcome of Immersive Learning

Skill acquisition constitutes the most prominent outcome examined in immersive learning research. Across higher education contexts, immersive environments have been associated with improvements in general and cognitive skills, including conceptual understanding, procedural accuracy, and problem-solving (Villegas-Ch et al., 2024). In health sciences education, for example, VR simulations are widely used to support clinical training, enabling students to rehearse complex procedures without exposing patients to risk (Chance, 2025). Similarly, engineering education has leveraged immersive simulations to enhance learners' understanding of complex systems, spatial relationships, and technical workflows (Suhail et al., 2024).

Regardless of such positive results, the literature points to a tendency toward narrowing in the conceptualization of skills. General or cognitive skills are the focus of most studies, whereas psychomotor, professional, and social-communication skills receive relatively little attention (Abd El-Sattar, 2025). Such a one-sided approach is important, given that higher education is becoming increasingly focused on comprehensive graduate skills such as collaboration, flexibility, and communication (Tang, 2024). Immersive learning situations, such as those Stiver et al. (2025) contend, have untapped potential to aid complex skills acquisition, but the potential is underutilized because of methodology-limiting factors and insufficient measures to operationalize both outcomes.

Student Engagement in Immersive Learning Environments

Together with skill acquisition, student engagement is often mentioned as one of the mechanisms by which immersive technologies impact learning. Immersion in contexts is commonly conceptualized as

a multidimensional construct that includes affective, behavioral, and cognitive dimensions (Ghanbaripour et al., 2024). An increase in affective involvement, including enjoyment, interest, and perceived involvement, is reported in many studies, especially in VR-based settings, where learners develop a strong feeling of presence (Yuan and Gao, 2024). Engagement is, however, mainly considered a by-product rather than a theoretically supported construct. Although affective engagement is typically measured, behavioral and cognitive engagement are not measured consistently, which restricts the explanatory value of engagement outcomes (Chen and Chu, 2024). Besides, engagement is often discussed as a state of being rather than as a process that coexists with skill development. According to Watson et al. (2025), such a conceptual vagueness creates a challenge in that it is hard to tell whether engagement only co-exists with immersive learning or is a mediator of learning outcomes. As a result, the interdependence between engagement and the acquisition of skills is insufficiently theorized in the literature.

Disciplinary Concentration and Educational Contexts

Immersive learning research is highly concentrated in the fields of education, health sciences, and engineering, as highlighted by the allocation of research in this field. Because of their reliance on applied learning, simulation, and procedural training, these areas are quite close to the capabilities of immersive technologies (Lawson McLean and Lawson McLean, 2024). Conversely, other disciplines, e.g., business, social sciences, and sports studies, are underrepresented, although more people are becoming interested in experiential and skills-based learning in these areas (Strobel and Gerling, 2025).

The significance of this disciplinary imbalance in the extrapolation of current results is obvious. In technically oriented or clinical settings, effective pedagogical strategies might not be relevant to disciplines that focus on abstract thinking, interpersonal interaction, and reflective learning (Li, 2024). This suggests that existing conceptualizations of immersive learning are influenced by a comparatively limited set of epistemological traditions, necessitating a more extensive disciplinary investigation.

Geographic Distribution and Contextual Gaps

The immersive learning studies are not evenly distributed geographically, and the majority originate in Europe, East Asia, and North America. These areas have the advantage of highly developed technological infrastructure, institutional resources, and funding opportunities that can be used to experiment with immersive learning (Huang and Hu, 2025). Conversely, studies in developing areas are few, which also casts doubt on the applicability and availability of context. Researchers have highlighted the role of cultural, institutional, and infrastructural influences in determining the methods of adoption and immersion in immersive technologies (Colamatteo et al., 2024). In the absence of broader geographic representation, available data can be prone to the propagation of context-specific findings that may not be representative of realities in higher education worldwide. This gap needs a scientific mapping of regional patterns and contextual effects, and not case studies.

Limitations of Existing Reviews and the Need for Integrated Synthesis

Despite the existence of several review studies on immersive technologies in education, most are rather narrow in scope, covering a specific technology, field, or outcome. Most reviews focus on effectiveness measures without considering trends in the breadth of disciplinary focus, the variety of outcomes, and geographical distribution (Poggianti et al., 2025). In addition, there is a lack of reviews that systematically consider skill acquisition and engagement in terms of the conceptual interdependence between the two variables. Such constraints justify the need for a systematic review of the literature that brings together a variety of immersive technologies, accounts for both skills and engagement effects, and conducts a cross-disciplinary and cross-regional analysis. This approach allows for the view of immersive learning as a sophisticated educational phenomenon, not a technology-based intervention (Adewumi, 2024). By filling these gaps, the current research addresses the call to include more holistic and analytically rigorous syntheses of research on immersive learning in higher education.

Methodology

Review Design and Rationale

This study adopted a systematic literature review (SLR) design to synthesize and critically examine empirical research on immersive learning technologies, with particular attention to learning-related outcomes and dominant research patterns. A systematic approach was selected to ensure transparency, replicability, and methodological rigor, while also allowing for interpretive synthesis beyond mere aggregation of findings (Friedl-Knirsch et al., 2024). Unlike scoping reviews, which prioritize breadth, or meta-analyses, which require statistical homogeneity, the present review sought to balance structured evidence identification with thematic interpretation, making it especially suitable for a field characterized by conceptual diversity and methodological heterogeneity (Varsha P S et al., 2024).

Immersive learning research spans multiple technologies (VR, AR, MR, XR), disciplinary contexts, and outcome constructs. As noted by Llanos-Ruiz et al. (2025), such diversity complicates direct quantitative comparison and necessitates an approach capable of identifying patterns, emphases, and omissions across studies. Accordingly, this review was guided by a synthesis-oriented logic, aiming not only to document what has been studied, but also to interrogate how immersive learning has been framed, operationalized, and evaluated in contemporary scholarship.

Search Strategy and Data Sources

A comprehensive search strategy was developed to capture peer-reviewed empirical studies examining immersive technologies in learning contexts. Major academic databases commonly used in educational technology and interdisciplinary research, such as Scopus and Web of Science, were selected due to their extensive coverage and indexing reliability (Tene et al., 2024). The search was conducted using combinations of technology-related terms (e.g., “virtual reality,” “augmented reality,” “mixed reality,” “extended reality”) and learning-related keywords (e.g., “learning,” “education,” “training,” “skills,” “engagement”).

To ensure conceptual consistency, synonymous terms and abbreviations were consolidated during the screening process, recognizing that immersive technologies are often described using overlapping or inconsistent terminology in the literature (Dhouib et al., 2025). Searches were limited to peer-reviewed journal articles published in English, reflecting the dominant language of scholarly dissemination in this field and ensuring methodological transparency.

This study follows the PRISMA guidelines to ensure transparency and replicability. A comprehensive literature search was conducted using two major databases: Scopus and Web of Science.

The search strategy was developed using relevant keywords related to immersive technologies and higher education. Boolean operators (AND, OR) were used to combine search terms and refine results: synonyms within each concept were connected with OR, and the main concept groups were combined with AND.

The final search strings applied in each database are presented below:

Scopus Search Query:

```
TITLE-ABS-KEY(("augmented reality" OR "virtual reality" OR "mixed reality" OR
"extended reality" OR "immersive technology" OR XR)
AND
("higher education" OR university OR college OR "tertiary education")
AND
("skill acquisition" OR "skill development" OR competence OR
"learning outcome" OR "knowledge gain" OR "performance improvement"))
AND (LIMIT-TO(DOCTYPE,"ar"))
AND (LIMIT-TO(LANGUAGE,"English"))
AND PUBYEAR > 2016 AND PUBYEAR < 2025
```

This query retrieved 604 articles from Scopus

Web of Science (WoS) Search Query:

```
TS=(("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "immersive
technology" OR XR)
```

AND
("higher education" OR university OR college OR "tertiary education")
AND
("skill acquisition" OR "skill development" OR competence OR "learning outcome" OR "knowledge gain"
OR "performance improvement"))
AND DT=(Article)
AND LA=(English)

This query retrieved 265 articles from WOS.

Inclusion and Exclusion Criteria

Clear inclusion and exclusion criteria were applied to ensure relevance and analytical coherence. Studies were included if they:

- (1) empirically examined immersive technologies (VR, AR, MR, or XR);
- (2) were situated within an educational, training, or learning-related context; and
- (3) reported at least one learning-related outcome, such as skill acquisition, engagement, or closely related constructs.

Studies were excluded if they were purely conceptual, technical, or descriptive without empirical data; focused solely on system development without learner outcomes; or examined entertainment or gaming contexts unrelated to learning objectives. Conference papers, book chapters, and dissertations were also excluded to maintain consistency in peer-reviewed evidence.

This filtering approach reflects concerns raised by [Dhouib et al. \(2025\)](#) that reviews of immersive learning often conflate technical innovation with pedagogical impact, thereby obscuring meaningful educational insights. Accordingly, this review prioritized outcome-oriented empirical studies to maintain a clear pedagogical focus.

Screening Process and Study Selection

The study selection process followed established PRISMA guidelines to ensure systematic identification, screening, and inclusion of relevant studies. Initial database searches yielded a broad pool of records, which were first screened for duplicates prior to eligibility assessment.

Titles and abstracts were then independently screened against predefined inclusion criteria using Rayyan to enhance screening consistency and reduce selection bias. Full-text screening was subsequently conducted to confirm methodological relevance and alignment with learning-related outcomes.

Disagreements or ambiguous cases were resolved through repeated review and consensus discussion between reviewers, ensuring consistency in decision-making and reducing the risk of arbitrary exclusion.

The final sample comprised 61 empirical studies, representing the contemporary body of research on immersive learning in higher education. A PRISMA flow diagram summarizing the study selection process is presented in Figure 1.

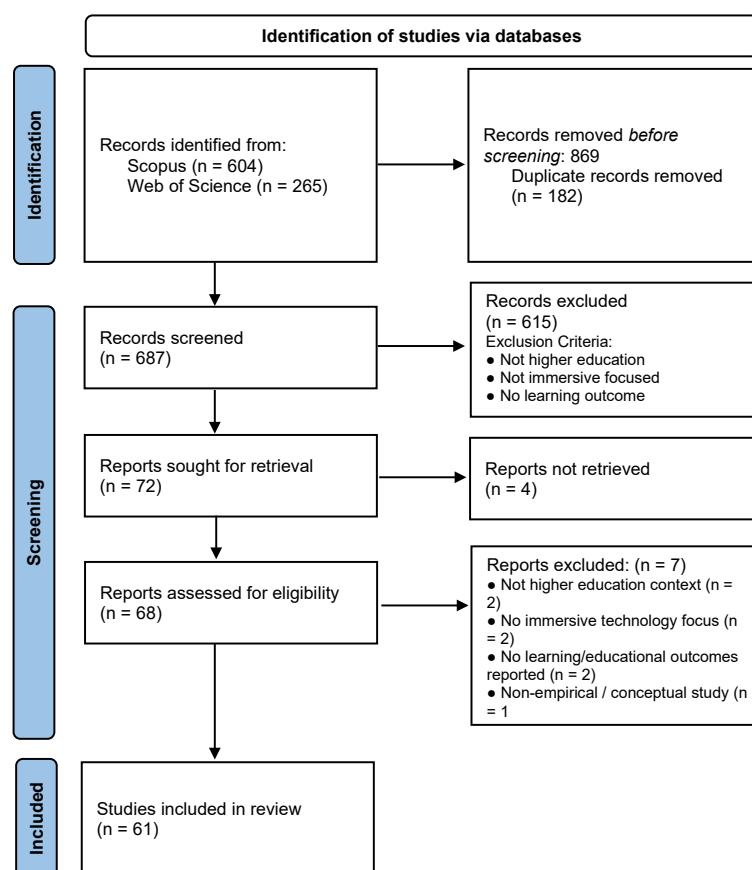


Figure 1. PRISMA flow diagram

Data Extraction and Coding Framework

An information extraction protocol was devised in a structured format to record descriptive and analytical information for each study. Data obtained comprised publication characteristics, disciplinary setting, immersive technology type, learning setting, and reported outcome focus and direction. Instead of the variables being perceived as discrete categories, they were coded in order to provide a cross-dimensional analysis where technology, context, and outcomes relationships would be pursued.

The coding structure was progressively improved during the extraction process, which is in line with best practices in systematic synthesis, in which categories are modified in response to the data (Khatab et al., 2024). As an example, the outcome focus was initially considered broadly, but it was narrowed to studies that investigated skills and engagement, and/or both, in response to repeated patterns across the literature (Lee et al., 2024).

Analytical Approach and Synthesis Strategy

Data synthesis proceeded in two complementary stages. First, a descriptive synthesis was conducted to identify dominant research characteristics, such as disciplinary concentration and the prevalence of technology. This step provided an empirical overview of how immersive learning research is currently structured. However, descriptive patterns alone were insufficient to address the study's objectives. Accordingly, a second stage of thematic synthesis was undertaken to interpret how immersive technologies were conceptualized and evaluated across studies. This involved identifying recurring emphases, such as the privileging of skill acquisition over engagement, as well as notable absences, including limited exploration of mixed or neutral outcomes. As argued by Ke et al. (2025), such interpretive synthesis is critical for moving beyond frequency counts toward theory-informed insight. Importantly, numerical values were used selectively to support key observations rather than to dominate the narrative. This approach aligns with calls for systematic reviews to prioritize meaningful interpretation over exhaustive quantification in heterogeneous fields (Durak et al., 2026).

Quality Considerations and Trustworthiness

While formal risk-of-bias scoring was not applied due to methodological heterogeneity across studies, several steps were taken to enhance the review’s trustworthiness. These included transparent inclusion criteria, consistent coding procedures, and careful alignment between research questions, analysis, and reporting. Furthermore, the focus on peer-reviewed journal articles ensured a baseline level of methodological quality. The review does not claim to represent all immersive learning research exhaustively; rather, it offers a systematic and analytically robust snapshot of dominant trends and gaps. Such positioning is consistent with contemporary views that systematic reviews should be interpreted as theory-building and agenda-setting exercises, rather than definitive mappings of an entire field (Benli and Kocaman, 2026).

To complement the thematic synthesis, we conducted a focused extraction and narrative-content analysis of reported outcomes from the 61 studies. Key findings on skill development, engagement, knowledge acquisition, confidence, and technology-specific effects were systematically compiled. These data were organized thematically to highlight dominant patterns, innovative practices, and contextual insights, enabling a richer understanding of the educational impacts of immersive technologies. This step ensured that the review captured both quantitative trends and qualitative nuances, bridging descriptive characteristics and the interpretive insights presented in the Findings section.

Methodological Positioning and Contribution

By integrating systematic procedures with interpretive synthesis, this methodology enables a nuanced examination of immersive learning research that goes beyond surface-level trends. The approach is particularly suited to identifying imbalances in outcome focus, disciplinary silos, and technology dominance, which collectively shape how immersive learning is understood and applied. As such, methodological design directly supports the study’s aim of informing future theoretical development, empirical design, and practical implementation in immersive learning research.

This review synthesized 61 empirical studies examining the use of immersive technologies in higher education. Findings are organized around research characteristics, technology adoption, learning outcomes, discipline-specific patterns, and geographic distribution, emphasizing emerging patterns, gaps, and insights rather than exhaustive counts.

Research Characteristics and Dominant Patterns

Analysis of the research landscape reveals that education and health sciences dominate studies on immersive learning, collectively accounting for over 60% of the literature. Engineering/STEM contributes a substantial but smaller share, while social sciences, business, and sports sciences remain underrepresented, highlighting a clear disciplinary bias. This concentration suggests that immersive technologies are primarily applied where procedural, cognitive, or technical skill development is critical, leaving significant opportunities for creative, interpersonal, and social applications, as shown in the publication trend in Figure 2.

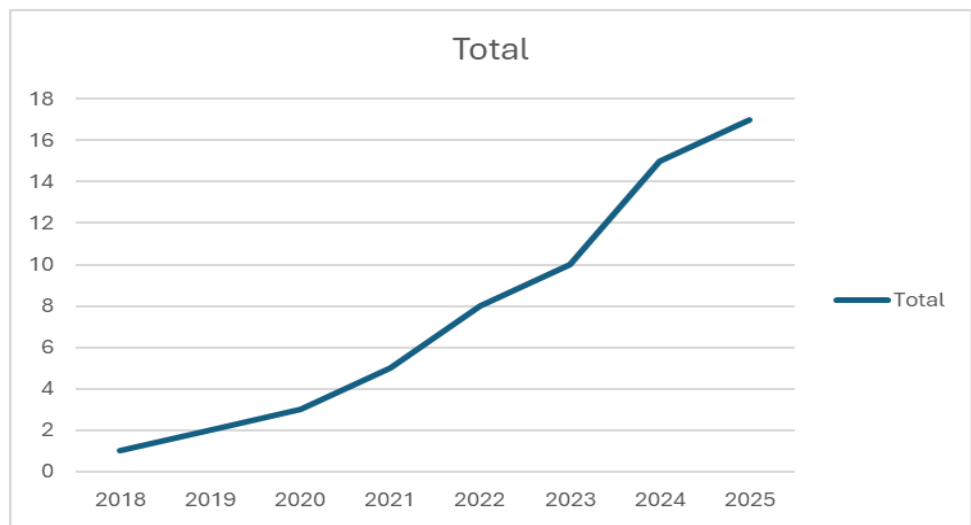


Figure 2. Publication Trend

The disciplinary breadth indicates that while most studies focus on a few core areas, there is a slow trend toward diversification. This pattern reflects both research priorities and technology suitability, as VR and XR are more readily integrated into education, health, and engineering curricula (See Table 1).

Table 1. Overall Research Characteristics of Immersive Learning Studies (N = 61)

Dimension	Dominant Pattern	Evidence (n, %)
Academic Context	Education and health sciences dominate; limited social uptake	Education: 24 (39.3%); Medical / Health Sciences: 15 (24.6%); Engineering / STEM: 13 (21.3%); Social Sciences / Business: 4 (6.6%); Sports Sciences: 4 (6.6%)
Technology Emphasis	VR is dominant; XR represents a substantial secondary stream	VR: 32 (52.5%); XR: 18 (29.5%); AR: 10 (16.4%); MR: 1 (1.6%)
Disciplinary Breadth	Narrow concentration with emerging diversification	Core disciplines (Education, Health, Engineering): 52 (85.2%); Other fields (Social Sciences, Sports): 9 (14.8%)
Outcome focus	Integrated examination of skills and engagement outcomes	Only skills (19.67%), only engagement (21.31%), both Skills and engagement (59.02%)
Outcome direction	Largely positive reported effects with minimal neutrality	Largely positive reported effects with minimal neutrality

Source: Author's own construction

Table 1 indicates a strong disciplinary concentration of immersive learning research in education and health sciences, with limited representation from social sciences, business, and sports. VR dominates as the primary technology, while XR shows growing adoption and AR and MR remain underutilized. Most studies adopt an integrated focus on both skills and engagement, reflecting a holistic evaluation of learning outcomes. Overall, reported effects are largely positive, though the scarcity of neutral findings suggests the need for more critical and diversified investigations.

Technology Adoption Across Disciplines

VR is the dominant technology, appearing in more than half of the studies, particularly in health sciences and sports. Its prevalence reflects VR's affordances for immersive, hands-on practice and realistic simulations. XR has emerged as a secondary stream, frequently applied in engineering and education for blended learning environments that combine cognitive, professional, and experiential skill development. AR, though less common, is strategically adopted where lightweight, context-sensitive interventions are needed. MR is almost absent, suggesting an untapped avenue for research.

These patterns show that technology choice is not random: VR is favored where high fidelity and presence are critical, XR is used for flexible, integrated learning, and AR supports practical, accessible interventions. This underscores the need to align technology with educational goals and learners' needs.

Table 2. Discipline-wise Distribution of Technologies and Learning Outcomes

Discipline	AR (n)	VR (n)	XR (n)	Dominant Skill Focus	Dominant Engagement Focus
Education	4	12	7	General, Cognitive	Affective, Behavioral
Engineering	2	5	6	Cognitive, Professional	Cognitive
Health Sciences	2	9	4	Cognitive, Psychomotor	Affective
Social Sciences	1	2	1	Cognitive	Affective
Business	1	0	0	Cognitive, Professional	Affective
Sports	0	4	0	Psychomotor	Behavioral

Source: Author's own construction

The integrated analysis in Table 2 shows that the adoption of immersive technologies and associated learning outcomes varies systematically across disciplines. VR is dominant in health sciences and sports, reflecting its suitability for simulation-based and psychomotor skill development. XR is more prevalent in engineering and education, supporting applied and professional competencies through blended learning approaches. Across disciplines, cognitive and general skills are most frequently targeted, while

affective engagement remains the dominant engagement outcome. In contrast, social sciences and business fields remain underrepresented, with limited exploration of diverse skill sets such as communication and collaboration. These patterns suggest that technology adoption is closely aligned with disciplinary learning objectives rather than being randomly distributed.

Table 3. *Immersive Technologies and Learning Outcomes: Integrated Synthesis*

Outcome Domain	Sub-Category	VR	AR	XR	Key Insight
Skills	General	15	3	9	Core strength across all technologies
	Cognitive	3	2	3	Strong in VR and XR
	Professional	5	2	1	XR supports applied skills
	Psychomotor	1	0	2	Dominated by VR
	Social/Communication	1	1	1	Underexplored
Engagement	Affective	4	4	4	Most dominant across all technologies
	Behavioral	5	1	1	Limited evidence
	Cognitive	3	0	1	Underreported
	Self-belief	4	2	2	Moderate presence
	Presence	3	0	1	Strong in VR

Source: Author's own construction

Table 3 provides an integrated synthesis of the associations between immersive technologies and different learning outcomes. VR shows strong alignment with general, cognitive, and psychomotor skills due to its high level of immersion and simulation capabilities. XR is more closely linked to professional and applied competencies, reflecting its role in blended and flexible learning environments. AR primarily contributes to cognitive and affective outcomes through context-sensitive, lightweight interventions. Across all technologies, affective engagement emerges as the most consistently reported outcome, highlighting the role of immersive environments in enhancing motivation, presence, and learner confidence. In contrast, behavioral and cognitive engagement remain underexplored, indicating a gap in understanding how immersive learning translates into deeper learning processes and active participation.

Geographic Distribution

Research is concentrated in Europe (34%) and East Asia (21%), with Southeast Asia and North America contributing moderately. Other regions, including Latin America, Africa, and Oceania, are underrepresented, pointing to a global imbalance in research activity. Regional adoption patterns also vary: VR dominates in Europe and East Asia, XR is increasingly used in North America and Europe, and AR appears more in Southeast Asia. These trends suggest that regional infrastructure, research priorities, and access to technology shape the adoption of immersive learning, offering insight into where future studies could expand geographically.

Table 4. *Regional Patterns in Immersive Learning*

Region	No. of Papers)	Percentage	Key Countries
Europe	21	34.43%	Spain (4), Netherlands (3), Denmark (3), UK (2), Slovakia (2)
East Asia	13	21.31%	China (9), Taiwan (3), Japan (1)
Southeast Asia	9	14.75%	Indonesia (3), Thailand (3), Malaysia (2)
North America	9	14.75%	United States (6), Mexico (3)
Middle East	4	6.56%	Saudi Arabia, Iran, Palestine, Turkey (1 each)
Latin America	3	4.92%	Ecuador, Peru, Mexico (1 each)
Africa	2	3.28%	Egypt (2)
Oceania	2	3.28%	Australia (2)
Total	61	100%	

Source: Author's own construction

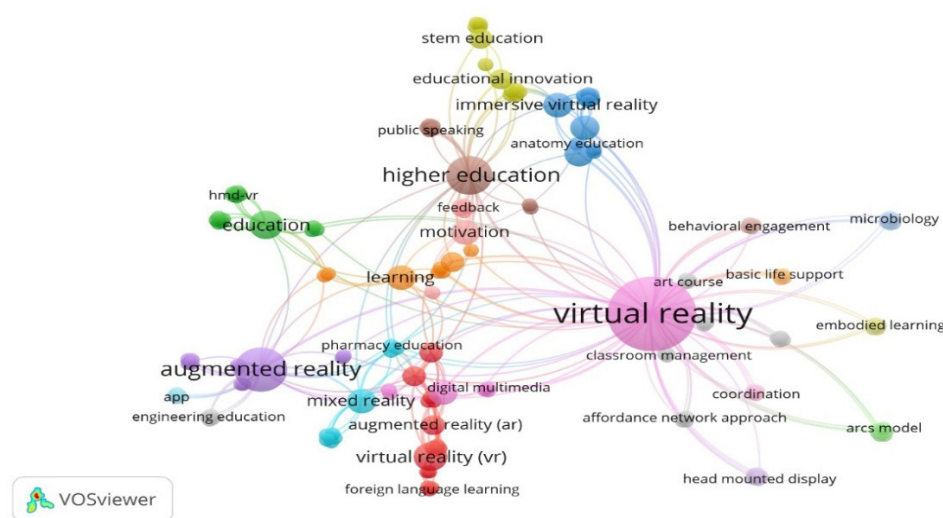


Figure 3. Keyword Co-occurrence Network

Figure 3, generated in VOSviewer, a keyword co-occurrence network, visualizes the conceptual structure of immersive learning research. Virtual reality emerges as the dominant, most centrally connected node, underscoring its foundational role across educational contexts. Closely linked clusters around higher education, learning, motivation, and engagement suggest a strong emphasis on pedagogical outcomes. In contrast, adjacent nodes such as augmented reality, mixed reality, and STEM education reflect expanding technological diversification. The network highlights both core instructional applications and emerging interdisciplinary integrations, illustrating a maturing yet still evolving research landscape.

Discussion

The present systematic review highlights the growing adoption of immersive technologies in higher education, with VR, XR, and AR emerging as the primary tools for enhancing learning experiences. The concentration of research in education and health sciences underscores a clear disciplinary preference, suggesting that immersive technologies are most readily applied in domains requiring procedural, cognitive, or technical skill development. While these areas have effectively leveraged immersive tools, the relative underrepresentation of social sciences, business, and sports disciplines suggests untapped potential for immersive learning in domains that emphasize collaboration, communication, and higher-order thinking (Kittel et al., 2024; Krouglov, 2024).

The bias towards designs based on quantitative analysis in the students included in the study indicates that the research questions are designed to address the measurable gains in skills. In contrast, few quantitative or mixed-method designs indicate a gap in the research to address how engagement and performance outcomes are facilitated and experienced by learners (Fernandes et al., 2023). This knowledge can be critical because the motivational and affective components of the learning process may be as important as the acquisition of skills, especially in immersion settings where presence and self-efficacy can impact the learning process (Thomann et al., 2024).

Technology-specific patterns reveal that VR dominates due to its capacity to deliver high-fidelity, immersive simulations, which are particularly effective in health sciences and sports training. XR, often deployed in blended learning settings, appears to facilitate professional skill development and affective engagement, offering flexibility that allows integration of cognitive and applied learning objectives. AR, although less prevalent, demonstrates meaningful contributions to cognitive and affective outcomes, particularly in educational and business contexts, highlighting its potential for context-sensitive, lightweight interventions. MR remains largely absent, representing an emerging frontier where future research could explore the simultaneous integration of cognitive, psychomotor, and affective dimensions, especially in complex or multi-step learning tasks (Bödding et al., 2025).

The observed patterns in the adoption and outcomes of immersive technologies can be more meaningfully understood through established learning theories rather than only descriptive trends. From a constructivist perspective, immersive environments such as VR and XR allow learners to actively construct knowledge through interaction and contextualized experiences, which may explain their strong association with cognitive and procedural skill development. This aligns with experiential learning theory, in which learning is enhanced through concrete experience and reflective engagement, particularly in simulation-based environments commonly used in the health sciences and engineering. At the same time, the dominance of affective engagement outcomes can be interpreted through the lens of self-regulated learning, as immersive technologies appear to enhance motivation, presence, and confidence, which are critical precursors for autonomous learning processes. However, the limited evidence on behavioral and cognitive engagement suggests that these technologies are not yet consistently supporting deeper self-regulation strategies such as planning, monitoring, and reflection. In addition, cognitive load theory offers an important explanation for the uneven effectiveness across technologies. While high-immersion environments like VR can enhance learning by increasing realism, they may also impose extraneous cognitive load if not carefully designed, potentially limiting their effectiveness in complex or abstract learning tasks. In contrast, AR-based applications may reduce cognitive overload by embedding information within real-world contexts, thereby supporting more efficient knowledge processing. Taken together, these theoretical perspectives suggest that the effectiveness of immersive technologies depends not only on their level of immersion but also on how well they are aligned with learning processes, cognitive capacity, and learner self-regulation.

Additional understanding comes from discipline-based as well as geographic patterns. The correlation between VR and health sciences and sports has been associated with domain-specific affordances, and XR use in engineering and education means that it can be used to create integrated and hybrid learning experiences (Samala et al., 2024). Eurocentric and East Asian geographic concentration also limits the generalizability of the results, as regions such as Latin America, Africa, and Oceania are underrepresented, casting doubt on the cultural, infrastructural, and pedagogical transferability (Akinradewo et al., 2025).

Limitations and Future Directions

These research restrictions can be overcome in future studies by diversifying immersive learning research studies by discipline and location sub-areas, using a wider variety of technologies, and incorporating more comprehensive engagement systems. More focus on MR and AR would further research on blended and context-aware learning experiences, and longitudinal and mixed-methods designs would make the experiences and motivations of learners, along with interaction patterns, more comprehensive than immediate performance improvements. To enhance pedagogical integration, technology choices can be further aligned with the intended learning outcomes, including VR for procedural mastery, XR for applied and professional competencies, and AR for cognitive scaffolding and motivation. Taken together, these guidelines provide a way to move research on immersive learning beyond technology-based experimentation towards theoretically grounded, context-specific, and scalable educational interventions that can bring the full potential of immersive technologies in higher learning to life.

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Conflict of interests

The authors declare no conflict of interest.

AI Declaration

The authors used generative AI tools, specifically ChatGPT and Grammarly, for language editing and formatting purposes only. The authors retain full responsibility for the accuracy, originality, and integrity of the manuscript.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author (s).

Institutional Review Board Statement

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Author Contributions

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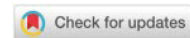
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Employee Perceptions of Reward Systems in Public Institutions: Evidence from the Republic of North Macedonia

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Abstract: It has always been an issue in the human resource management selecting the right rewards for the employees especially in the public institutions. Many public institutions are unable to identify the types of rewards which are best used to foster employees' work satisfaction. The study aims are to evaluate how reward systems in public institutions influence employee perception and to analyze their impact on job satisfaction, quality of work, and employee retention in the public sector of North Macedonia. Data were collected via self-administered questionnaire of 153 employees in public institutions in North Macedonia. Reliability and validity of the measurement instrument are confirmed through Cronbach's alpha (0.777) and factor analysis. Descriptive statistics, correlation analysis, and regression analysis are applied to test the proposed hypotheses. The results indicate that the re-ward system has a positive but weak effect on job satisfaction ($\beta = 0.142$, $p = 0.079$), quality of work ($\beta = 0.146$, $p = 0.071$), and employee retention ($\beta = 0.144$, $p = 0.075$), with none of the effects reaching statistical significance. Additional hierarchical re-gression analysis suggests that demographic characteristics partially influence these relationships, while the contribution of reward systems remains limited. The findings imply that reward systems in public institutions play a secondary role in shaping employee outcomes, while other factors such as job security, intrinsic motivation, and institutional stability may be more influential. The study contributes to the limited empirical literature on public sector reward systems in North Macedonia and offers practical insights for policymakers and managers seeking to improve human resource management practices.

Keywords: reward system, public institutions, employee, North Macedonia.

Introduction

Reward systems constitute an important component of human resource management in public institutions, as they are expected to influence employee job satisfaction, quality of work, and retention. In public-sector institutions, reward mechanisms are shaped by institutional regulations, budgetary limitations, and standardized employment conditions, which often differentiate them from reward practices in the private sector.

Public institutions within the European Union generally apply more structured and transparent reward systems, emphasizing merit-based principles, accountability, and performance evaluation (Crețu et al., 2024). These systems increasingly combine financial and non-financial rewards, including professional development opportunities, recognition schemes, and work-life balance initiatives, with the aim of enhancing employee engagement and institutional performance. Such practices are supported by clearly defined legal frameworks and performance management systems that align individual contributions with institutional objectives (OECD, 2017).

In contrast, public institutions in the Republic of North Macedonia, and the wider region, tend to predominantly rely on seniority-based pay systems, while performance-based reward mechanisms are implemented to a considerably lesser extent. Differences in administrative capacity, financial resources, and institutional culture contribute to less standardized reward practices, which may reduce their effects

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on employee motivation. Consequently, the effectiveness of reward systems in influencing employee attitudes and behavior in the public sector remains an open empirical question.

Recent research highlights the growing importance of non-monetary rewards and intrinsic motivation in public-sector employment; however, empirical evidence on employee perceptions of reward systems and their impact on job satisfaction, quality of work, and retention in North Macedonia is still limited (de Juana-Espinosa and Rakowska, 2018; Danevska et al., 2024). Most existing studies focus on formal reward policies rather than on how employees evaluate these systems in practice (Gerhart and Fang, 2015).

Also, have demonstrated that employee engagement in public organizations is significantly influenced by intrinsic motivational factors, leadership support, and public service motivation, which contribute to stronger work engagement and positive organizational outcomes (Alamri, 2023).

This research gap provides the foundation for the present study, which examines employee perceptions of reward systems in public institutions in the Republic of North Macedonia and analyzes their impact on job satisfaction, quality of work, and employee retention. By focusing on employee perceptions rather than formal reward policies alone, the study contributes to a deeper understanding of motivation and performance in the public sector.

Against this background, the aim of this study is to analyze employee perceptions of reward systems in public institutions in the Republic of North Macedonia and to examine their impact on job satisfaction, quality of work, and employee retention. Using a quantitative research approach based on survey data and statistical analysis, the study seeks to contribute empirical insights to the literature on public-sector human resource management and to provide practical implications for improving reward system design in public institutions.

Reward system in public institutions in the Republic of North Macedonia

Rewarding and motivating employees represents one of the most challenging areas of human resource management, particularly in the public sector. A reward system refers to the set of financial and non-financial compensation mechanisms provided to employees in recognition of their contribution, performance, and achievement of organizational objectives. A well-designed reward system is expected to enhance employee productivity and institutional effectiveness, while for employees it represents a source of motivation, job satisfaction, and professional commitment.

In the public sector of the Republic of North Macedonia, the reward system is implemented through a formal framework of performance evaluation, compensation, promotion, and professional development. Over the past decade, significant reforms have been introduced leading to implementation of various human resource management standards, aimed at improving transparency, fairness, and accountability.

According to the applicable legal framework, every employee in the public sector is entitled to a salary and reimbursement of work-related expenses under conditions defined by law, collective agreements, and employment contracts. Fundamental principles and criteria for rewarding, promotion, professional development, and performance evaluation are regulated by the Law on Administrative Officers, the Law on Public Sector Employees, and other relevant legal acts (Law on Administrative Servants, 2025 and Law on Public Sector Employees, 2025).

The reward system in public institutions follows the concept of total rewards, which includes both monetary and non-monetary components. Monetary rewards consist primarily of salaries and allowances, while non-monetary rewards include promotion opportunities, professional development, recognition, and performance-based incentives. Performance evaluation represents a key prerequisite for rewarding and is conducted annually, assessing employees based on efficiency, quality of work, goal achievement, and commitment.

Administrative officers are evaluated on a scale from 1 to 5, resulting in performance ratings from "A" to "E". These ratings are directly linked to career advancement opportunities and serve as a prerequisite for promotion. Salary structure consists of a basic component—determined by education level, job position, and years of service—and an exceptional component, which includes allowances for special working conditions, overtime, shift work, and risk exposure (Law on Administrative Servants, 2025, article 54).

Promotion is considered an important form of rewarding in the public administration system. The promotion process is regulated, transparent, and based on clearly defined criteria, including previous performance ratings, years of service, and the absence of disciplinary measures. Additionally, the system ensures the principle of adequate and equitable representation, with the aim of ensuring fairness, equal

access to career advancement opportunities, and non-discriminatory treatment for all employees throughout the promotion procedure.

Professional development is also recognized as a form of rewarding. Administrative officers have both the right and the obligation to participate in continuous professional development activities based on individual development plans. These activities aim to improve skills and competencies and contribute to the overall efficiency and quality of public administration.

Despite the existence of a comprehensive legal and institutional framework, the effectiveness of reward systems in influencing employee satisfaction, performance, and retention depends largely on how these mechanisms are perceived and experienced by employees in practice. This context provides the foundation for the empirical analysis conducted in this study.

Literature review and hypotheses development

Reward systems represent a fundamental element of human resource management and play a crucial role in attracting, motivating, and retaining employees while aligning individual contributions with institutional objectives. In public institutions, reward systems are expected not only to stimulate performance but also to promote fairness, accountability, transparency, and socially responsible behavior. Compared to the private sector, reward systems in public administration are more strongly regulated, standardized, and oriented toward equity and procedural fairness rather than exclusively toward performance-based compensation (OECD, 2016).

Public-sector reward systems generally consist of fixed salaries, allowances, benefits, job security, career advancement opportunities, and professional development mechanisms. Due to the bureaucratic nature of public administration, the use of performance-contingent financial incentives is often limited. This institutional structure reflects the need to ensure equal treatment, political neutrality, and transparency in public employment practices. However, modern human resource management increasingly recognizes that compensation alone is insufficient for sustaining employee motivation and institutional effectiveness.

The concept of total rewards provides a broader framework for understanding employee compensation and motivation. According to total reward theory, reward systems include not only direct financial compensation, but also non-financial and intrinsic rewards such as recognition, autonomy, professional development, meaningful work, feedback, and work-life balance (Milkovich et al., 2019). Effective reward systems should therefore be strategically aligned with institutional objectives, employee expectations, and public-service values in order to improve both employee satisfaction and organizational performance.

Existing literature consistently demonstrates that successful public-sector reward systems combine financial and non-financial dimensions. Financial rewards include salaries, bonuses, allowances, and benefits, while non-financial rewards encompass recognition, opportunities for career development, flexible work arrangements, autonomy, and job stability. Self-determination theory emphasizes that intrinsic and non-financial rewards often produce stronger and more sustainable motivational outcomes than purely financial incentives, particularly in public-service environments where employees are frequently motivated by social contribution and professional identity (Ryan and Deci, 2000).

Empirical research confirms that reward systems significantly influence employee performance, organizational commitment, job satisfaction, and employee retention in public institutions. Research conducted in public institutions in Rwanda indicates that compensation, recognition systems, career development opportunities, and employee benefits positively affect employee performance. Importantly, non-monetary rewards such as career development and fringe benefits were found to have stronger motivational effects than direct financial compensation, emphasizing the importance of long-term professional security and growth opportunities (Kampororo et al., 2021).

Similarly, studies focusing on local government institutions in Botswana reveal that ineffective and poorly managed reward systems contribute to reduced employee motivation, low institutional commitment, and weaker service quality. Transparent and equitable reward practices, on the other hand, improve employee satisfaction and retention (Tshukudu, 2020). These findings indicate that the effectiveness of reward systems depends not only on their formal structure, but also on employees' subjective perceptions of fairness, transparency, and adequacy.

Employee perceptions represent a critical mediating factor between reward structures and work-

related outcomes. Research suggests that employees' attitudes toward institutions are shaped less by the objective level of rewards and more by their subjective evaluations of procedural justice, recognition, and equity (Lincoln and Kalleberg, 1990). When employees perceive reward systems as fair, transparent, and aligned with their contributions, they are more likely to demonstrate stronger organizational commitment, higher work engagement, and improved job performance.

In public administration, intrinsic rewards often outweigh extrinsic rewards in shaping employee motivation and satisfaction. Public servants are frequently driven by public-service values, professional ethics, and the opportunity to contribute to society. Consequently, meaningful work, recognition, and opportunities for professional growth play a particularly important role in sustaining employee engagement and institutional commitment (Belle and Cantarelli, 2015; Perry et al., 2010).

Recent literature increasingly emphasizes that reward systems must adapt to changing workforce expectations, digital transformation, demographic changes, and labor market competition. Contemporary public-sector organizations face growing pressure to modernize reward practices in order to improve institutional resilience, employee engagement, and organizational effectiveness. As a result, reward systems are now viewed not only as compensation mechanisms, but also as strategic instruments for improving institutional performance and public-service quality (World Bank, 2021; CIPD, 2023).

Recent empirical studies further highlight the importance of fairness, transparency, and perceived organizational support in public institutions. Research conducted in European public administrations demonstrates that procedural justice, transparent evaluation criteria, and equal access to career advancement opportunities significantly strengthen employee trust and motivation, even within relatively rigid compensation systems (Kwon and Kim, 2020). Similarly, newer generations of employees increasingly value flexibility, autonomy, continuous learning opportunities, and work-life balance alongside traditional financial compensation.

The COVID-19 pandemic and the acceleration of digital transformation have additionally reshaped employee expectations regarding reward systems. Flexible working arrangements, mental health support, digital working conditions, and opportunities for continuous professional development are now recognized as important components of modern reward systems. OECD reports suggest that institutions capable of combining traditional compensation mechanisms with employee-centered reward practices achieve higher levels of motivation, retention, institutional adaptability, and organizational resilience (OECD, 2023).

Digital transformation has also introduced new challenges in reward management. Employees increasingly expect more personalized, transparent, and performance-sensitive reward systems supported by digital HRM technologies and continuous feedback mechanisms. Recent studies indicate that organizational culture and leadership quality strongly influence how employees perceive reward fairness and institutional support during periods of organizational change (Vnoučková et al., 2022).

In transition and developing economies, public-sector reward systems are additionally shaped by fiscal constraints, political reforms, administrative traditions, and institutional capacity limitations. Reform efforts often fail when reward policies are not aligned with employee expectations and workplace realities (World Bank, 2021). In the Western Balkans, including North Macedonia, public administration reforms have intensified the importance of understanding employee perceptions regarding fairness, transparency, adequacy, and motivational effectiveness of reward systems.

For North Macedonia specifically, empirical research examining employee perceptions of reward systems in the public sector remains limited. Potential discrepancies between formal reward policies and their practical implementation may negatively affect employee morale, productivity, institutional trust, and employee retention. Therefore, examining how employees perceive both financial and non-financial rewards represent an important step toward understanding motivation and organizational commitment in the Macedonian public sector.

Reward Systems and Job Satisfaction

Job satisfaction reflects employees' overall evaluation of their work experience and institutional environment. Prior research suggests that perceived fairness and adequacy of rewards significantly contribute to job satisfaction (Lincoln and Kalleberg, 1990). When employees perceive reward systems as transparent, equitable, and aligned with performance, they are more likely to experience higher levels of satisfaction.

Although public institutions rely less on performance-contingent pay than private organizations (OECD, 2016; OECD, 2023), the perception of recognition and professional development opportunities

may still positively influence satisfaction levels. Therefore, the following hypothesis is proposed:

H₁: Reward system in public institutions positively impacts employee job satisfaction in performing day-to-day tasks.

Reward Systems and Quality of Work

Reward systems are also designed to enhance performance and work quality. According to self-determination theory (Ryan and Deci, 2000), extrinsic rewards may reinforce task engagement when they support competence and autonomy. Empirical evidence indicates that appropriately structured reward systems can enhance employee performance and effort in public-sector institutions (Kampororo et al., 2021).

Even within highly regulated systems, employees who perceive recognition and advancement opportunities as meaningful may be more motivated to maintain high-quality work standards. Therefore:

H₂: Reward system positively impacts employee work quality and motivation in performing day-to-day tasks

Reward Systems and Employee Retention

Employee retention is influenced by both economic and psychological factors. While public-sector employment is often associated with job security, perceived fairness and recognition remain important determinants of long-term institutional commitment (Tshukudu, 2020). Employees who perceive reward systems as fair and supportive are more likely to develop stronger attachment to their institutions and lower turnover intentions.

Accordingly, the third hypothesis is formulated as:

H₃: Reward system positively impacts employee retention in public institutions

The three hypotheses (H₁–H₃) summarize the expected positive relationships between reward system and job satisfaction, work quality and employee retention. Testing this framework enables an empirical comparison of the relative importance of different levels in shaping employee intentions in a public institution. The next section describes the research design, measurement scales and analytical procedures employed to examine these relationships.

Materials and methods

The methodological approach of this study was formulated based on the specific nature of the researched issue and the need to use appropriate data sources. This study used a self-administered questionnaire to collect primary data, consisting of clear and concise questions, developed in accordance with the relevant laws and bylaws. The questionnaire was prepared in Google Docs and distributed online to employees from various public institutions in the Republic of North Macedonia. The selection of respondents was carried out using random sampling, in order to ensure the representativeness of the data. Participation in the survey was anonymous, and all collected information was used solely for the purpose of this research. The study resulted in 153 (one hundred and fifty-three) valid responses, which were used for the empirical analysis. The survey ran from March 1st to June 30th, 2025.

This research aims to raise awareness of the need for continuous investment in the development of human resources in public institutions and to encourage managerial staff to continuously propose possible approaches for ongoing performance evaluation and rewarding, in line with institutional needs and implemented activities.

The questionnaire consisted of a total of 13 questions, aimed at identifying the actual situation in the public sector, providing a detailed analysis of the importance and necessity of human resource management through the processes of motivating and rewarding employees, and offering recommendations for improving these processes in public institutions in the Republic of North Macedonia.

The questionnaire contained questions in a closed-ended format and logically connected questions measured using a 5-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. The introduction part was designed to gather basic information like age, sex and working period in the institution. The other questions concern of type of reward for the employees, how they are satisfied with the current reward, does the reward system in their institution is fair and transparent, does reward system influence

on the job satisfaction, quality of work or employee retention.

The questionnaire items were grouped into four main variables: reward system, job satisfaction, quality of work, and employee retention. The reward system variable included following items: q4: How satisfied are you with the current reward system in your institution; q6: Do you believe that the reward system in your institution is fair and transparent; q7: Do you believe that the reward system in your institution is aligned with the organizational goals and tasks; q8: How often are rewards given in your institution, and q13: How effective is the communication with supervisors regarding the reward system in your institution. The job satisfaction variable was measured through the item q9: How would you rate the impact of the reward system on your job satisfaction. Variable quality of work included item q12: Does the performance evaluation and reward system affect the quality of work in your institution and Employee retention variable was assessed through the item q10: Do you think that the reward system contributes to better employee retention in your institution.

Therefore, the use of questionnaire as a data collection method enables the examination of potential relationships among the variables included in the study, as well as the main research questions. According to [BiHu, \(2021\)](#), the data collection process generally involves questionnaire design, data collection, statistical analysis, interpretation of findings, and presentation of conclusions. The sample size is adequate for the exploratory factor analysis and multiple regression analysis, particularly when the measurement instrument demonstrates acceptable reliability and validity and when the number of predictors remains limited ([Kyriazos, 2018](#)).

Results

The paper analyzes the influence of reward system in public institutions on employee satisfaction. The aim of this research is to define the reward system and to obtain results regarding the impact of the reward system on employee productivity in the public sector of the Republic of North Macedonia.

Table 1 presents descriptive data analyses, based on the data collected, it is identified that the majority of the respondents are between 35 and 44 years old (54.9%), followed by those between 45 and 54 years old (22.4%), between 25 and 34 years old (11.8%) and 55 and above only 9.8%. The smallest group were those under 25 years old (1.3%). This suggests that the findings of the study primarily reflect the perceptions and experiences of employees with active involvement in institutional processes and institutional experience in public institutions. The dominance of experienced employees enhances the credibility of the results, as respondents are likely to have a well-formed understanding of reward systems, performance evaluation, and career advancement processes. Their assessments are therefore based on prolonged exposure to institutional practices rather than short-term impressions.

Out of the 153 respondents, 113 respondents (73.9%) were female, 40 respondents (26.1%) were men. This has shown that the most of the employees in the public institutions are females. According to the work experience on the public institutions 64.1% work more than 10 years and none of the respondents had worked for less than one year. The high proportion of respondents with more than ten years of work experience indicates that the survey responses are based on employees who have more work experience and institutional knowledge. The absence of respondents with less than one year of experience further suggests that the findings reflect informed and stable perceptions of the reward system. The demographic and employment characteristics of the respondents in this study are consistent with officially published reports on employment in the public administration in the Republic of North Macedonia. The predominance of middle-aged employees, the higher representation of female respondents reflects the structural features of the public-sector workforce identified in official national statistics. This alignment indicates that the sample accurately represents the composition of employees in public institutions and supports the reliability and relevance of the collected data ([Ministry of Information Society and Administration, 2024](#)).

Table 1. Descriptive results

		Frequency	Percent	Std. Deviation
How old are you?	Under 25 years	2	1,3	
	25-34	18	11,8	
	35-44	84	54,9	
	45-54	34	22,2	
	55 and above	15	9,8	
	Total	153	100	0,845
Sex	Male	40	26,1	
	Female	113	73,9	
	Total	153	100	0,441
How long have you been working in public institutions in the Republic of North Macedonia?	Less than 1 year	0	0	
	1-3 years	12	7,8	
	4-6 years	24	15,7	
	7-10 years	19	12,4	
	More than 10 years	98	64,1	
	Total	153	100	1,005

Source: author's own research

Following the descriptive statistics, a reliability analysis using Cronbach's alpha was conducted to verify the reliability of the scale before proceeding with further statistical analyses.

Cronbach's alpha is applied to measure reliability on variables. The reward system scale demonstrates acceptable internal consistency, exceeding the commonly accepted threshold of 0.7 (Table 2). This confirms that the selected items reliably measure a single underlying construct and are suitable for further inferential analysis.

Table 2. Alpha Coefficient of reliability on variables

Cronbach's Alpha	N of Items
0.777	5

Source: author's own research

To confirm the adequacy of the data for structure detection we use factor analysis. Sampling adequacy is good (KMO = 0.865) which means that we have robust data. Bartlett's test for sphericity is highly significant, at the 0.00 level, indicating that the variables are highly correlated and can be used for factor analysis.

Table 3. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.810
Approx. Chi-Square	284.241
Bartlett's Test of Sphericity	df
	15
	Sig.
	0.000

Source: author's own research

Correlation analysis is a tool for representing the closeness of one related variable to another and serves as an intermediate analytical step that provides preliminary empirical evidence regarding whether theoretically related variables are associated in practice.

Table 4 shows that none of the correlation coefficients between the reward system and the other variables exceed the threshold of 0.50, indicating weak and moderate correlations at the 0.05 significance level. Between quality of work and employee retention ($r = 0.540$, $n = 153$, $p \leq 0.05$) and between job satisfaction and quality of work ($r = 0.470$, $n = 153$, $p \leq 0.05$), moderate to strong correlations are observed. These findings indicate that job satisfaction and quality of work represent key factors influencing employee retention within the institution.

Furthermore, job satisfaction shows moderate correlations to employee retention ($r = 0.439$, $n = 153$, $p \leq 0.05$), confirming its important role in retaining employees. In contrast, the reward system does not show statistically significant correlations with job satisfaction, quality of work, or employee retention at the 0.05 level, suggesting that its influence on these outcomes is limited or indirect. Overall, the results imply that institutions primarily enhance employee retention by improving job satisfaction and work quality,

rather than relying solely on reward system mechanisms.

These findings are consistent with previous studies emphasizing that intrinsic motivation, organizational support, and work environment often play a more significant role in public-sector employee attitudes than purely financial incentives (Belle and Cantarelli, 2015; Perry et al., 2010).

Table 4. *Correlation analysis*

		Reward_System	job satisfaction	quality of work	employee retention
Reward_System	Pearson Correlation	1	0.142	0.146	0.144
	Sig. (2-tailed)		0.079	0.071	0.075
	N	153	153	153	153
Job satisfaction	Pearson Correlation	0.142	1	0.470**	0.439
	Sig. (2-tailed)	0.079		0.000	0.000
	N	153	153	153	153
quality of work	Pearson Correlation	0.146	0.470**	1	0.540
	Sig. (2-tailed)	0.071	0.000		0.000
	N	153	153	153	153
employee retention	Pearson Correlation	0.144	0.439**	0.540**	1
	Sig. (2-tailed)	0.075	0.000	0.000	
	N	153	153	153	153

Source: author's own research

After comparing the strength of the correlation coefficient regression analysis has been run to test the study's hypotheses concerning the impact of the reward system on employee outcomes.

Table 5 presents a summary of regression analyses conducted to test the three research hypotheses. The results indicate that the reward system has a positive effect on job satisfaction, quality of work, and employee retention; however, effect sizes are small. The explained variance across all models is low, with R Square values ranging from 2.0% to 2.1%, suggesting that reward systems play a limited role in shaping employee outcomes in public institutions. Consequently, Hypotheses H₁, H₂, and H₃ are not statistically significant.

Table 5. *Summary of Regression Results for Hypotheses*

Variables	Hypothesis	β (Reward System)	R Square	Adjusted R Square	F	Sig. (p)
Job satisfaction	H ₁	0.142	0.020	0.014	3.124	0.079
quality of work	H ₂	0.146	0.021	0.015	3.303	0.071
employee retention	H ₃	0.144	0.021	0.014	3.207	0.075

Note: N = 153. p < 0.05

Source: author's own research

The low explained variance across all models indicates that additional organizational and psychological factors may play a more important role in shaping employee attitudes and behavior. In highly regulated public-sector environments, employees may perceive reward systems as standardized administrative mechanisms rather than strong motivational tools. Similar findings have been reported in studies examining public-sector motivation in transitional administrative systems, where institutional stability and job security often outweigh the motivational influence of formal reward structures (OECD, 2025; Tshukudu, 2020).

Table 6 presents the results of hierarchical regression analyses conducted as a robustness check. In the first step, age and years of experience were entered as control variables. In the second step, the reward system was added to the models. The results indicate that the reward system contributes positively to job satisfaction, quality of work, and employee retention after controlling for demographic characteristics. However, the additional explained variance (R Square Change) is modest, ranging from 1.9% to 2.4%, and the effects are marginally significant at the 10% level. These findings suggest that while reward systems play a role in shaping employee outcomes in public institutions, their impact is limited and influenced by other factors.

Table 6. Results of the hierarchical linear regression analysis for robustness check

Dependent Variable	Predictor	Standardized Coefficients β	t	Sig.	R Square Change	R Square
Job satisfaction	Age	0.228	2.772	0.006	0.019	0.071
	Working experience	-0.119	-1.444	0.151		
	Reward system	0.140	1.761	0.080		
Quality of work	Age	0.045	0.533	0.595	0.024	0.031
	Working experience	-0.102	-1.203	0.231		
	Reward system	0.155	1.912	0.058		
Employee retention	Age	0.161	1.924	0.056	0.019	0.045
	Working experience	-0.053	-0.634	0.527		
	Reward system	0.139	1.720	0.087		

Source: author's own research

Discussions

The purpose of this study was to examine whether reward systems in public institutions influence employee job satisfaction, quality of work, and retention. The findings indicate that although the relationships between the reward system and employee outcomes are consistently positive, their strength is weak and not statistically significant. This pattern is observed across all three tested hypotheses, suggesting a stable and coherent empirical outcome rather than random statistical variation.

The findings are also aligned with more recent public administration studies emphasizing that public servants are increasingly motivated by intrinsic rewards, professional identity, and organizational stability rather than by direct financial compensation alone (Andersen et al., 2021). Recent OECD reports similarly suggest that standardized public-sector compensation systems reduce the motivational impact of performance-based rewards, particularly in transitional administrative environments characterized by centralized regulation and limited managerial flexibility (OECD, 2025).

The weak impact of reward systems may be explained by the specific characteristics of public institutions in the Republic of North Macedonia. Public-sector employment is typically associated with high job security, standardized salary structures, and limited performance-based incentives. As a result, employees may perceive rewards as an expected entitlement rather than as a motivational mechanism capable of significantly influencing their behavior. This interpretation aligns with public administration literature, which emphasizes that internal motivation, professional identity, and commitment to public service often play a more dominant role than rewards in employee attitudes.

These findings are consistent with more recent studies emphasizing the importance of intrinsic motivation and organizational support in public-sector institutions. Alamri (2023) found that employee engagement in public organizations is strongly influenced by transformational leadership and public service motivation, suggesting that non-financial motivational factors may play a more significant role in shaping employee attitudes and work engagement than formal reward mechanisms alone. This may explain the relatively weak influence of reward systems identified in the present study.

An important factor is the structure of the sample. The majority of respondents have more than ten years of work experience, indicating a highly stable workforce with extensive institutional knowledge. Such employees are likely to evaluate reward systems based on long-term experience rather than short-term expectations, which may further reduce the observable impact of rewards on satisfaction, performance, and retention. Employees in later career stages often place greater value on job stability, security, and institutional continuity than on performance-based rewards or short-term incentives. Consequently, reward systems may be perceived as a formal and expected component of employment rather than a strong motivational driver. Furthermore, the limited representation of younger employees suggests that early-career expectations, such as rapid advancement, performance-linked rewards, and flexible incentive structures, are less influential in shaping the overall results. This reinforces the interpretation that essential factors and structural characteristics of public-sector employment play a more prominent role in employee attitudes than reward mechanisms alone.

The correlation analysis revealed strong relationships between job satisfaction, quality of work,

and employee retention, suggesting that these factors are closely interconnected. This finding implies that improving work conditions, institutional support, and meaningful job design may be more effective strategies for enhancing retention than focusing exclusively on reward systems. This may be particularly relevant in the context of the Republic of North Macedonia as a developing country, where public-sector employees may place greater value on job stability, institutional support, and working conditions than on formal reward mechanisms, which are often perceived as standardized and limited.

Overall, the results suggest that while reward systems remain an important component of human resource management, their effectiveness in public institutions is constrained by structural and institutional factors. These findings contribute to a more detailed understanding of employee motivation in the public sector and highlight the need for a broader approach to managing human resources beyond formal reward mechanisms.

Conclusions

In any public institution employee performance is key towards achieving specific goals. Employee perceptions of reward systems in public institutions in the Republic of North Macedonia depend on job satisfaction, quality of work, and employee retention. The research results demonstrate that reward systems have a positive but limited influence on these outcomes and do not represent a primary driver of employee behavior in the public institutions.

The findings indicate that public-sector employees' attitudes and performance are shaped more strongly by factors such as job stability, institutional environment, and internal motivation than by reward mechanisms alone. This suggests that policymakers and managers should complement reward systems with broader human resource strategies focused on professional development, recognition, employee engagement, and supportive leadership.

The report on public administration in the Republic North Macedonia (OECD, 2025) highlights that public-sector reward systems remain highly standardized, centrally regulated, and weakly linked to measurable performance outcomes. This institutional context helps explain why the present research identified positive yet weak and statistically non-significant effects from the research hypotheses. In environments where rewards are largely determined by formal criteria such as position classification and tenure, employees may perceive compensation as an entitlement rather than a motivational instrument. Consequently, the limited empirical support for the hypotheses does not necessarily contradict motivational theory but instead reflects structural constraints that reduce the strategic influence of reward systems in public institutions.

This study contributes to the literature in several ways. It extends the theoretical understanding of reward systems in public-sector context by providing empirical evidence from a transitional administrative environment, where compensation structures are highly standardized and centrally regulated. Offers practical and policy-relevant insights by demonstrating that reward systems exert only a limited influence on job satisfaction, quality of work, and employee retention, suggesting the need for better alignment between performance evaluation and incentive mechanisms. The study enhances regional scholarship by addressing the scarcity of quantitative research on human resource management practices in public institutions in the Republic of North Macedonia.

Future research could expand this study by incorporating qualitative methods, examining specific types of rewards in greater detail, or comparing public and private sector employees to further explore differences in motivational dynamics.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Institutional Review Board Statement

Not applicable.

Author Contributions

Conceptualization, M.B.K., V.P., N.P.A, M.D. and I.P.; methodology, M.B.K., V.P. N.P.A and I.P.; software, M.B.K. and M.D.; formal analysis, M.B.K., M.D., V.P., N.P.A and I.P.; writing—original draft preparation, M.B.K., M.D., V.P., N.P.A and I.P.; writing—review and editing, M.B.K., V.P., M.D., N.P.A and I.P. All authors have read and agreed to the published version of the manuscript.

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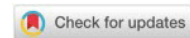
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Reaction-Time Patterns in an Emotional Face–Word Stroop Task among Lower Secondary School Students: A Pilot Study

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Abstract: This pilot study examined whether incongruent facial expressions and Vietnamese emotion labels were associated with longer reaction times than congruent pairings in lower secondary school students. Six Vietnamese students in Grades 6 to 8 completed a 130-trial Emotional Face–Word Stroop Task comprising 70 congruent and 60 incongruent trials. Reaction time was the primary measure, while accuracy was summarized separately. Mean reaction time was longer for incongruent trials than for congruent trials, with an average difference of 175.87 milliseconds and a 95 percent confidence interval from 104.28 to 247.46 milliseconds. Overall accuracy was 81.3 percent and was descriptively lower for incongruent trials than for congruent trials. An exploratory analysis across three broader stimulus groups produced a condition-by-group pattern, but this result was interpreted as task-specific because trial frequencies were unequal and the corresponding cells differed in emotional composition. All participants completed the task, with completion times ranging from 7.76 to 11.12 minutes. The findings showed an observed within-sample congruency pattern in this Vietnamese-language task, but they do not support population-level or stable emotion-specific conclusions. Future studies should use larger and more diverse samples, balanced stimulus categories, prespecified reaction-time preprocessing rules, controlled testing conditions, and sensitivity analyses restricted to correct responses. This pilot provides procedural and behavioral information for refining the task and designing future developmental, educational, and cross-cultural research.

Keywords: *Emotional Stroop Task, attentional interference, reaction time, emotion processing, students.*

Introduction

The Stroop task is a well-established and widely used experimental paradigm for examining interference and cognitive control. First introduced by Stroop (1935), the task requires participants to respond to a task-relevant stimulus dimension while managing interference from a competing, task-irrelevant dimension. In the classic color–word Stroop task, participants name the ink color of words that themselves denote color names. Responses are generally faster and more accurate when the ink color and word meaning are congruent, whereas incongruent trials tend to produce longer reaction times and more errors, a pattern known as the Stroop interference effect (MacLeod, 1991; Stroop, 1935). Contemporary reviews continue to characterize the Stroop effect as robust, while indicating that it may involve contributions from multiple levels of processing and more than one locus of attentional selection (Parris et al., 2022).

Building on the classic paradigm, emotional Stroop tasks have been developed to examine how emotional meaning influences attentional performance. In a common version of the task, emotional and neutral words are presented in different ink colors, and participants are instructed to identify the ink color while ignoring the word meaning (Joyal et al., 2019; Straub et al., 2022; Wielgopalan et al., 2025). Emo-

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tional words often produce longer reaction times than neutral words, although the magnitude and direction of this difference may vary across stimulus sets, task designs, and participant groups (Joyal et al., 2019; McKenna, 1986; Straub et al., 2022; Wielgopolan et al., 2025; Williams et al., 1996). This reaction-time difference is commonly used as an index of emotional interference or attentional bias, but it does not uniquely identify the cognitive mechanism producing the effect (Joyal et al., 2019; Straub et al., 2022).

Although classic and emotional Stroop tasks both involve interference during task performance, the sources of that interference can differ substantially across paradigms (Müller et al., 2025). In the classic task, interference arises when task-relevant color information competes with task-irrelevant word information and may involve both informational and task conflict (Parris et al., 2022). In emotional Stroop tasks, performance may be influenced by the emotional salience and semantic meaning of the stimuli, as well as by task demands, prior experience, and participant characteristics (Hsieh and Sharma, 2019; Imbir, Pastwa, et al., 2021; McKenna and Sharma, 2004; Williams et al., 1996). Emotional interference may therefore reflect multiple processes, including attentional capture and semantic or conceptual processing, with additional contributions from task-control and memory processes depending on the paradigm and participant characteristics (Hsieh and Sharma, 2019; Imbir, Pastwa, et al., 2021). This distinction is important because reaction-time differences alone cannot determine which processing component is responsible for the observed interference (Parris et al., 2022).

Emotional attention and interference can vary with the modality and configuration of the emotional stimuli used in a task (Lunn and Chen, 2022; Smolker et al., 2022). Face–word Stroop variants combine facial expressions and emotional language, creating conflict when the two sources of emotional information are inconsistent (Jamieson et al., 2023; Kuehne et al., 2019). Recent research indicates that emotional face–word Stroop paradigms can provide behavioral measures related to processing speed, inhibitory control, and emotional information processing in adolescent samples (Banich et al., 2019; Smolker et al., 2022). Studies of inconsistent emotional face–word signals further indicate that performance may involve cognitive control processes that regulate competition between task-relevant and task-irrelevant affective information (Banich et al., 2019; Jamieson et al., 2023; Kuehne et al., 2019). Behavioral measures such as reaction time and accuracy can characterize the interference pattern, but they do not by themselves identify the neural processes underlying that pattern (Jamieson et al., 2023; Kuehne et al., 2019).

Research has also examined whether emotional Stroop interference varies according to stimulus valence. Earlier studies reported greater interference for negative than for neutral or positive stimuli, which was interpreted as preferential attention to potentially threatening information (McKenna and Sharma, 1995; Pérez-Edgar and Fox, 2003). For example, Pérez-Edgar and Fox (2003) found that secondary school students responded more slowly to negative words than to neutral words, whereas responses to positive and neutral words did not differ. More recent evidence indicates that emotion perception can vary with developmental stage and stimulus presentation (Tsenkova et al., 2025). Within the emotional Stroop paradigm, performance may also depend on multiple affective dimensions, including interactions between valence and arousal and effects associated with subjective significance (Imbir, Duda-Góławska, et al., 2021). Emotional stimuli therefore do not produce a uniform interference pattern across task conditions, stimulus characteristics, or participant populations (Imbir, Duda-Góławska, et al., 2021; Joyal et al., 2019).

Several theoretical accounts have been proposed to explain emotional Stroop interference. Attentional-capture accounts propose that emotionally salient stimuli temporarily direct processing resources away from task goals, whereas threat-related accounts emphasize disruption by information with potential motivational relevance (Wentura et al., 2000; Williams et al., 1996). Response- and task-conflict accounts instead propose that interference can arise from competition at the response level and from competition between task sets, with their contributions depending partly on the stimulus–response structure and response requirements of the task (Hsieh and Sharma, 2019; Parris et al., 2022). These perspectives are not mutually exclusive. Rather, they suggest that observed interference may reflect multiple processes whose relative contributions can vary with task design, stimulus characteristics, and participant characteristics (Hsieh and Sharma, 2019; Joyal et al., 2019; Parris et al., 2022; Smolker et al., 2022).

Beyond stimulus characteristics, individual and contextual factors may also shape emotional Stroop performance (Ishikawa et al., 2021; Scrimin et al., 2019). Previous research has linked variation in Stroop-related emotional and attentional interference to anxiety, clinical status, and the personal or diagnostic relevance of the stimuli (Ishikawa et al., 2021; Joyal et al., 2019). In educational settings, students have shown attentional bias toward school-related stressors, with performance also varying according to indi-

vidual emotional characteristics and classroom context (Scrimin et al., 2016; Scrimin et al., 2019). More broadly, contextual factors such as stress, support, cognitive stimulation, and school or classroom environments have been identified as relevant pathways or protective factors in youth cognitive and academic outcomes (Rakesh et al., 2025). Together, these findings support further examination of emotional interference in school-aged populations in relation to attentional self-regulation, academic stressors, and classroom context (Scrimin et al., 2016; Scrimin et al., 2019). Longitudinal evidence also indicates that emotion regulation is closely linked to school-related well-being during adolescence (Beaumont et al., 2023).

Emotional face–word Stroop tasks combine two socially meaningful sources of emotional information and create conflict when facial expressions and emotion labels are inconsistent (Smolker et al., 2022). Recent research has applied emotional Stroop paradigms to adolescent samples across different cultural settings. For example, Lunn and Chen (2022) examined separate facial and lexical emotional Stroop tasks in Taiwanese adolescents, whereas Smolker et al. (2022) used a large-scale emotional face–word Stroop paradigm to examine task performance and its associations with cognition and psychopathology in a large adolescent cohort. Despite these developments, three gaps remain relevant. First, although word-based emotional Stroop paradigms remain prominent in the literature, comparatively less work has focused on facial–verbal emotional conflict in school-aged samples (Smolker et al., 2022). Second, research specifically focused on children and adolescents remains comparatively limited, particularly relative to the extensive adult and clinical literature (Lunn and Chen, 2022; Smolker et al., 2022). Third, emotional Stroop performance in Vietnamese adolescents remains an underexplored area. More broadly, cognitive neuroscience applications in Vietnamese educational research have been described as still developing (Shih-Tseng and Tran-Chi, 2019). Addressing these gaps is important because developmental stage and cultural context can shape emotion recognition and emotional processing (Möller et al., 2022), while task structure determines how competing facial and verbal emotional information generates response conflict (Smolker et al., 2022). Linguistic adaptation may also require careful consideration when emotional Stroop tasks are used across languages (Lunn and Chen, 2022). A Vietnamese-language pilot can therefore provide useful procedural and behavioral information for future developmental, educational, and cross-cultural studies.

The present small pilot study addressed these gaps using an Emotional Face–Word Stroop Task adapted for Vietnamese lower secondary school students. Unlike conventional emotional Stroop paradigms based on color naming, the present task required participants to judge whether a Vietnamese emotion label matched a facial expression. The study was designed to describe task implementation and within-subject performance patterns rather than to estimate population-level effects. The primary aim was to examine whether incongruent trials were associated with longer reaction times than congruent trials within the present sample. A secondary exploratory aim was to describe whether the condition-related reaction-time pattern varied across broader neutral, positive, and negative stimulus groups, given the mixed patterns reported in previous research (McKenna and Sharma, 1995; Pérez-Edgar and Fox, 2003). This secondary analysis was intended to characterize the present task configuration rather than to provide confirmatory evidence of stable emotion-specific effects. The analyses were expected to inform task refinement and the design of larger hypothesis-driven studies.

Materials and methods

Participants

The study included six lower secondary school students recruited through convenience sampling from the researchers' personal networks and referrals. All participants were enrolled in Grades 6 to 8 at the time of data collection. The sample consisted of two female students (33.3%) and four male students (66.7%). One participant was in Grade 6 (16.7%), three were in Grade 7 (50.0%), and two were in Grade 8 (33.3%). Exact ages were not collected; therefore, participants' grade levels were used to indicate their educational stage.

Eligibility required current enrollment as a lower secondary school student, sufficient Vietnamese reading comprehension to understand the task instructions and emotion labels, written consent from a parent or legal guardian, verbal assent from the student, and willingness to complete the computerized task. No additional clinical or health-related exclusion criteria were applied, and no formal clinical, develop-

mental, or visual screening was conducted. Participants who ordinarily used corrective glasses completed the task using their usual eyewear. Before the task began, the researcher explained the instructions and demonstrated the required keyboard responses. No participant was excluded or withdrew after enrollment.

Recruitment was conducted independently of any secondary school, and no school served as a recruitment or data-collection site. The task was administered individually in home-based settings; therefore, school administrative permission was not applicable.

Study Design

The study employed a within-subject pilot design using an Emotional Face–Word Stroop Task. All participants completed congruent and incongruent trials involving seven emotion categories. Reaction time (RT) was operationalized as the response latency from stimulus onset to keypress for trials in which a response was recorded, irrespective of response accuracy, and served as the primary performance measure. Response accuracy was analyzed separately as a secondary measure. The study was designed to describe task implementation and within-subject performance patterns in a pilot sample, rather than to estimate population-level effects.

Emotional Face–Word Stroop Task

Stimuli

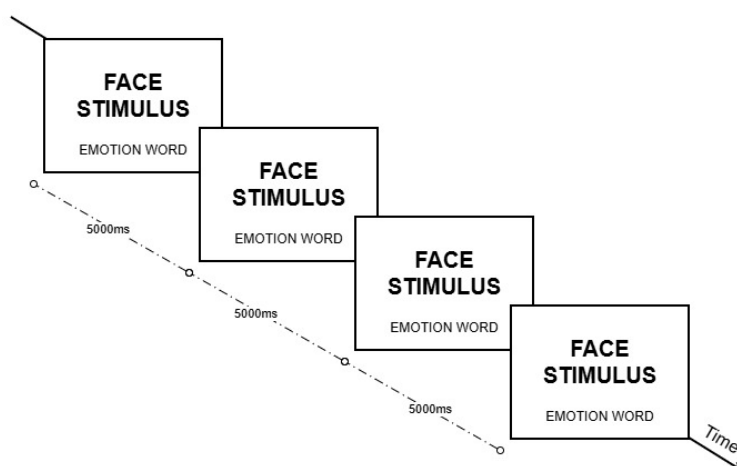
Facial stimuli were obtained from the Averaged Karolinska Directed Emotional Faces (AKDEF) database developed by [Lundqvist and Litton \(1998\)](#). The complete AKDEF set consists of 70 grayscale images depicting an averaged female face and an averaged male face, each displaying seven emotional expressions from five viewing angles. The expressions are afraid, angry, disgusted, happy, neutral, sad, and surprised, and the source images have a resolution of 562 × 762 pixels. The present task used all 70 images from the AKDEF set. These images were paired with Vietnamese emotion labels to construct 130 trials. The number of trials therefore refers to the number of face–label pairings, rather than the number of unique source images, and some images appeared in more than one pairing. Sad, angry, neutral, disgusted, surprised, and afraid expressions each appeared in 20 trials (15.4%), whereas happy expressions appeared in 10 trials (7.7%).

For the secondary exploratory analysis, trials were grouped as neutral (20 trials), positive (30 trials), and negative (80 trials). The positive group included happy and surprised trials, whereas the negative group included sad, angry, disgusted, and afraid trials. Surprise was provisionally classified as positive for this exploratory grouping. Because no happy-incongruent trials were presented, the positive cells were not compositionally equivalent across conditions. The positive congruent condition included both happy and surprised trials, whereas the positive incongruent condition included surprised trials only. This imbalance was explicitly considered when interpreting the exploratory stimulus-group analysis.

Although the task did not involve color–word naming, it followed a Stroop-like congruency framework in which participants responded to agreement or conflict between facial and verbal emotional information. Because the task required an explicit match–mismatch judgment, both the facial expression and the emotion label were relevant to the response. The manipulation therefore represented facial–verbal emotional congruency conflict rather than interference from a task-irrelevant dimension ([Smolker et al., 2022](#)).

Task Procedure

The task was programmed and administered using E-Prime version 1.1 ([Psychology Software Tools, 2020](#)). The English task instructions and emotion labels were translated into Vietnamese by bilingual members of the research team. Because the materials consisted of seven basic emotion terms and brief instructions, the translations were reviewed collaboratively for semantic clarity and age-appropriate comprehension. Given the limited and concrete nature of the materials, no formal back-translation or external linguistic validation was undertaken. Before the experimental trials began, the researcher explained the instructions orally, demonstrated the two response keys, allowed participants to ask questions, and confirmed that each participant understood the response procedure. No separate practice block was administered.



Each trial presented a facial expression together with a Vietnamese emotion label. Participants indicated whether the label matched the expression. The stimulus remained visible until a response was made or until the 5,000-ms response deadline was reached. The faces shown in the figure are schematic; the experimental stimuli were obtained from the AKDEF database (Lundqvist and Litton, 1998).

Figure 1. Example Trial Sequence in the Emotional Face–Word Stroop Task

No fixation cross was presented. On each trial, a facial image and a Vietnamese emotion label appeared simultaneously on the screen. Participants pressed the “1” key when the label matched the facial expression and the “2” key when the label did not match the expression. The facial stimulus and emotion label remained visible until the participant responded or the 5,000-ms response deadline was reached, and a keypress immediately terminated the stimulus display.

After each trial, feedback indicating a correct or incorrect response was displayed for approximately 1,000 ms. The next trial began immediately after the feedback display, with no separate intertrial interval. Because the task was brief, no scheduled breaks were provided. Across participants, total completion time ranged from 7.76 to 11.12 minutes, with a mean duration of 8.94 minutes. All participants received the same set of 130 trials, but trial order was randomized separately for each participant by E-Prime within a single mixed sequence. No additional counterbalancing or manually imposed restrictions on consecutive trial types were applied. Participants were instructed to respond as quickly and accurately as possible.

Apparatus and Software

The task was programmed and administered using E-Prime version 1.1 on the same Dell Precision 7550 laptop for all participants. The laptop had a 15.6-inch display, and responses were entered using its built-in keyboard. Using the same computer, display, keyboard, and software configuration standardized the administration conditions across participants. E-Prime recorded RT in milliseconds and automatically stored response accuracy.

Testing was conducted individually in a quiet and comfortable home-based setting. The researcher remained present throughout each session and made reasonable efforts to minimize noise, interruptions, and other external distractions. Timing precision was not independently benchmarked; however, the same hardware and software configuration was maintained across all testing sessions.

Data Collection and Measures

Data collection took place between May 2024 and October 2024. RT was operationalized as the interval between stimulus onset and the participant’s keypress for trials with a recorded response, irrespective of response accuracy. Accuracy was coded separately as 1 for a correct response and 0 for an incorrect response when a response was recorded. The response window was limited to 5,000 ms. When no response was made before the deadline, E-Prime recorded a system-coded RT value of 0 ms, and no response accuracy was recorded. Two timeout trials occurred across the sample. During data preparation, the corresponding analysis values for these timeout trials were recoded as 99 and designated as user-missing in SPSS.

The task yielded 780 trial-level records across six participants. Each participant was presented with 130 trials, including 70 congruent trials (53.8%) and 60 incongruent trials (46.2%). All trial records were

retained in the dataset; however, the two timeout trials were treated as missing for analyses requiring RT or accuracy. Participant-level condition means were therefore calculated from the available nonmissing observations within each condition. RT and accuracy were analyzed as separate performance indicators.

Data Analysis

Given the small pilot sample, the analyses were used primarily to characterize within-subject performance patterns, and the inferential findings were interpreted exploratorily rather than as population-level evidence. RT and accuracy were treated as separate performance indicators. RT analyses retained all recorded RTs irrespective of response accuracy; therefore, RTs from both correct and incorrect responses were included. The two timeout trials, for which no behavioral response was recorded, were designated as user-missing in SPSS and did not contribute to RT or accuracy calculations. No missing values were imputed. No RT trimming, winsorization, transformation, or distribution-based outlier exclusion was applied to the recorded RT values. Participant-level condition means were calculated from the available nonmissing RT observations within each condition.

For the primary within-subject comparison, participant-level mean RTs for congruent and incongruent trials were compared using a paired-samples *t* test. Given the sample size, distributional assumptions and inferential estimates were interpreted cautiously. The mean difference, its 95% confidence interval, and Cohen's d_z were reported to characterize the magnitude of the within-subject condition difference.

For the secondary exploratory analysis, a 2 (condition: congruent, incongruent) $\times$ 3 (broader stimulus group: neutral, positive, negative) repeated-measures analysis of variance was conducted using participant-level mean RTs. Because of the small sample size and unequal stimulus composition, this analysis was used to characterize patterns in the present task configuration rather than to provide confirmatory evidence of emotion-specific effects. Partial eta squared (η_p^2) was reported as an effect-size estimate. Sphericity was assessed using Mauchly's test, and Greenhouse–Geisser corrections were planned if the assumption was violated. Statistical analyses were conducted using IBM SPSS Statistics Version 26.

Results

Data Completeness and Trial Retention

All six participants completed the full task protocol, yielding 780 trial-level records. Two trials (0.3%) reached the 5,000-ms response deadline without a behavioral response. These timeout trials remained in the dataset but were treated as missing for analyses requiring RT or accuracy. Accordingly, 778 trials contained recorded behavioral responses. RTs from both correct and incorrect responses were retained in the RT analyses, whereas accuracy was analyzed separately.

Descriptive Statistics of Emotional Stroop Performance

Descriptive statistics for RTs across conditions and emotion categories are presented in Table 1. Mean RTs across individual emotion categories ranged from approximately 1,201 to 1,948 ms. Although the overall condition-level mean was higher for incongruent trials, patterns across individual emotion categories varied by condition. Therefore, the individual emotion results are presented descriptively, without inferential comparisons at that level.

Table 1. Descriptive Statistics of Reaction Times (ms) Across Conditions and Emotion Groups

Condition	Emotion Group	Emotion Name	Minimum	Maximum	Mean	Standard Deviation
Congruent	Positive	Happy	636	3381	1201	453
		Surprised	784	2578	1352	368
	Negative	Afraid	843	3997	1838	696
		Angry	607	3233	1555	594
		Disgusted	723	4739	1407	646
		Sad	626	4029	1768	639
Incongruent	Neutral	Neutral	737	4187	1689	677
	Positive	Happy	–	–	–	–
		Surprised	901	4250	1948	713
	Negative	Afraid	658	4715	1829	718
		Angry	735	3113	1620	545
		Disgusted	796	4992	1494	713
		Sad	862	3193	1772	604
	Neutral	Neutral	814	4970	1653	799

Note: Descriptive statistics are based on trial-level RT observations and are presented to characterize the observed RT distributions within the task. Timeout trials were treated as missing and were not included in these calculations.

Overall accuracy was 81.3%. Descriptive accuracy by condition is presented in Table 2. Mean accuracy was 86.19% ($SD = 4.11\%$) for congruent trials and 75.56% ($SD = 12.46\%$) for incongruent trials.

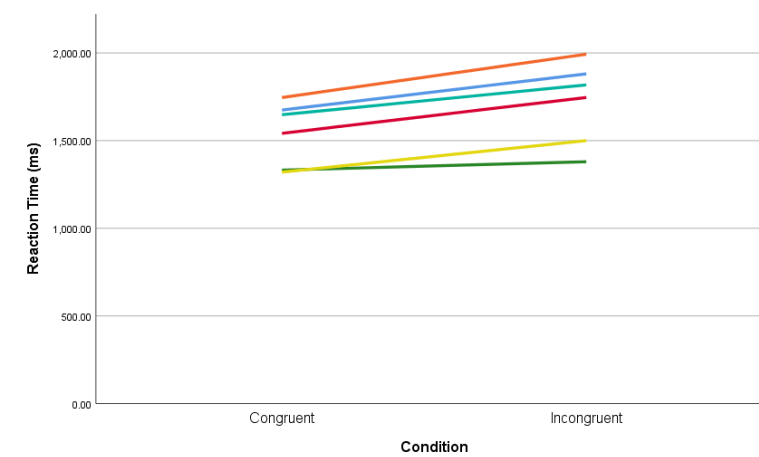
Table 2. Overall Accuracy

Condition	Mean Accuracy (%)	Standard Deviation (%)
Congruent	86.19	4.11
Incongruent	75.56	12.46

Note: Accuracy was calculated from trials with a recorded response; timeout trials were treated as missing

Condition Effect (Congruent vs. Incongruent)

The primary within-subject comparison examined whether mean RTs differed between congruent and incongruent trials. Participant-level mean RTs were longer for incongruent trials ($M = 1,719.50$ ms, $SD = 234.40$) than for congruent trials ($M = 1,543.63$ ms, $SD = 180.87$). An exploratory paired-samples t test indicated a condition difference, $t_{(5)} = 6.32$, $p = .001$, Cohen's $d_z = 2.58$. The mean difference was 175.87 ms, 95% CI [104.28, 247.46]. Within this six-participant pilot sample, the observed mean RT difference was in the expected direction; however, the inferential result is reported for exploratory purposes and should not be interpreted as providing a stable population-level effect estimate. Participant-level mean RTs for the two conditions are illustrated in Figure 2.



Each line represents an individual participant. Reaction times are shown as participant-level means

Figure 2. Reaction Times for Congruent and Incongruent Conditions

Exploratory Condition-by-Stimulus-Group Patterns

As a secondary exploratory analysis, a 2 (condition: congruent, incongruent) $\times$ 3 (broader stimulus group: neutral, positive, negative) repeated-measures analysis of variance was conducted using participant-level mean RTs. Because the task contained unequal numbers of trials across emotion categories and the positive cells differed in emotional composition across conditions, the analysis was used to characterize the observed pattern in the present task configuration rather than to test confirmatory valence-specific effects.

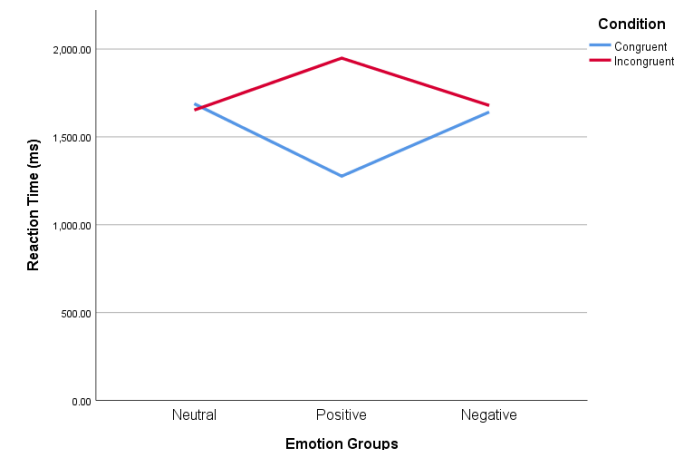
Table 3. Mean Reaction Times (ms) Across Conditions and Broader Stimulus Groups

Emotion Group	Congruent (Mean $\pm$ Standard Deviation)	Incongruent (Mean $\pm$ Standard Deviation)
Neutral	1688.68 $\pm$ 237.57	1652.57 $\pm$ 377.27
Positive	1276.33 $\pm$ 171.91	1948.30 $\pm$ 171.48
Negative	1641.64 $\pm$ 219.27	1678.92 $\pm$ 275.11

Note: Values represent participant-level means. The positive congruent condition included happy and surprised trials, whereas the positive incongruent condition included surprised trials only because no happy-incongruent trials were presented. The cells therefore differed in emotional composition, and comparisons involving the positive group should be interpreted descriptively.

Mauchly's tests were not statistically significant for either the broader stimulus-group effect or the Condition $\times$ Stimulus Group interaction ($p = .457$ and $p = .696$, respectively). Given the small pilot sample, however, these tests provided limited evidence regarding the sphericity assumption. For consistency with the original exploratory analysis, the uncorrected degrees of freedom are retained and reported descriptively.

The analysis yielded a main effect of condition, $F_{(1,5)} = 42.99$, $p = .001$, $\eta_p^2 = .90$. The main effect of broader stimulus group was not statistically significant, $F_{(2,10)} = 0.20$, $p = .83$, $\eta_p^2 = .04$. A Condition $\times$ Stimulus Group interaction was also observed, $F_{(2,10)} = 22.74$, $p < .001$, $\eta_p^2 = .82$. Because the positive congruent and incongruent cells did not contain the same emotion categories, the interaction is reported as a task-specific exploratory pattern rather than evidence of valence-specific interference. Given the small pilot sample and the non-equivalent emotional composition of the positive cells, these ANOVA results are reported solely as exploratory summaries of the observed task configuration. The associated p values and effect-size estimates should not be interpreted as stable estimates of population-level effects or as confirmatory evidence of valence-specific interference.



Note: The positive congruent and incongruent cells differed in emotional composition because happy trials were present only in the congruent condition. The figure is therefore intended to illustrate the observed task pattern rather than a confirmed valence-related effect.

Figure 3. Descriptive Reaction-Time Patterns Across Broader Stimulus Groups and Conditions.

Accuracy and Error Patterns

Overall accuracy was adequate rather than near either extreme of the response scale. Mean accuracy was descriptively lower for incongruent trials than for congruent trials. Descriptively, the combination of longer RTs and lower accuracy in the incongruent condition was not consistent with the conventional

pattern expected under a speed–accuracy trade-off. Because accuracy was not subjected to inferential testing, this interpretation remains descriptive.

Discussion

The present pilot study examined attentional processing in Vietnamese lower secondary school students using an Emotional Face–Word Stroop Task. Accordingly, the present paradigm is best understood as a Stroop-like facial–verbal congruency task rather than a conventional emotional color–word Stroop task in which emotional word meaning is task-irrelevant to the color-naming response. The primary focus was the within-subject difference in reaction time between congruent and incongruent trials, whereas patterns across broader stimulus groups were examined exploratorily. Overall, the results showed longer reaction times for incongruent trials, together with adequate descriptive accuracy across the sample. The exploratory analysis also indicated that condition-related reaction-time patterns differed across broader stimulus groups, although these differences require cautious interpretation because of the unequal stimulus composition.

The longer reaction times observed for incongruent trials are consistent with previous emotional face–word Stroop findings in adolescent samples (Smolker et al., 2022). In the present task, the incongruent condition was defined by a mismatch between facial and verbal emotional information rather than by conventional color–word conflict. The observed pattern suggests that evaluating mismatched emotional cues imposed additional processing demands, potentially engaging conflict-resolution and cognitive-control processes (Jamieson et al., 2023; Smolker et al., 2022). Given the pilot design, the result is best interpreted as a consistent within-sample condition pattern rather than as a stable estimate of a population-level effect. Nevertheless, it provides a useful basis for refining and evaluating this Vietnamese-language task in a larger sample.

Accuracy findings provided additional context for interpreting the reaction-time results. Mean accuracy was descriptively lower for incongruent trials than for congruent trials, while overall performance remained adequate. Descriptively, the combination of longer reaction times and lower accuracy in the incongruent condition was not consistent with the conventional pattern expected under a speed–accuracy trade-off. Because accuracy was not subjected to inferential testing, this interpretation remains descriptive.

The exploratory analysis further indicated that condition-related reaction-time differences varied across the broader stimulus groups. However, this pattern cannot be attributed confidently to emotional valence because the positive cells were not compositionally equivalent across conditions. The positive congruent condition included happy and surprised trials, whereas the positive incongruent condition included surprised trials only, and the numbers of neutral, positive, and negative trials were also unequal. The observed interaction may therefore reflect differences in stimulus composition, trial frequency, or their combination rather than a stable valence-specific effect. This cautious interpretation is consistent with evidence that emotional Stroop performance can vary as a function of valence and arousal (Imbir, Duda-Golawska, et al., 2021), while emotional face–word Stroop effects can also vary with distractor valence and the relative frequency of incongruent trials (Smolker et al., 2022). Accordingly, the present interaction is most appropriately viewed as a task-specific exploratory pattern that can inform the development of a more balanced stimulus design.

The study also has relevance for developmental and educational research. In educational settings, attentional bias and emotional interference have been associated with academic stressors, self-regulatory processes, and classroom context (Scrimin et al., 2016; Scrimin et al., 2019). Emotion regulation is also longitudinally related to school-related well-being during adolescence (Beaumont et al., 2023). Although these educational outcomes were not directly assessed, the present task provides a behavioral paradigm that could be incorporated into future studies examining how school-aged participants manage competing emotional information. The Vietnamese context also adds evidence from a comparatively underrepresented population in the emotional Stroop literature. Because emotion recognition and labeling may vary across developmental and cultural contexts, and because task translation can affect cross-language implementation, culturally and linguistically adapted paradigms are important for future comparative research (Lunn and Chen, 2022; Möller et al., 2022). The current findings therefore contribute preliminary procedural and behavioral information rather than direct evidence of cultural differences.

Several limitations should be considered. The pilot sample was small and recruited through convenience sampling, which limits the precision of effect-size estimates and the extent to which the observed patterns can be generalized. Exact ages were not collected, which also restricted developmental interpretation beyond grade level. In addition, the unequal stimulus distribution, particularly the absence of happy-incongruent trials, limits conclusions about valence-specific or emotion-specific effects. Testing was conducted in home-based settings rather than a laboratory; however, the same laptop, software configuration, researcher-administered procedure, and efforts to minimize distractions were used across all sessions. No separate practice block was administered, so early-trial performance may have reflected task-familiarization effects, particularly given the participants' developmental stage. The reaction-time analysis retained both correct and incorrect responses when an RT was recorded because the outcome was defined as overall response timing. Timeout trials without a recorded behavioral response were treated as missing. Future studies could prespecify sensitivity analyses restricted to correct-response trials to evaluate the robustness of this analytic choice. Finally, the translated materials were reviewed collaboratively but did not undergo formal linguistic validation, and the hardware-software timing configuration was not independently benchmarked. These limitations should be considered when interpreting the magnitude and robustness of the observed within-sample condition pattern and identify important priorities for task refinement and future confirmatory investigation.

Future research should examine emotional face–word Stroop performance in larger and more diverse samples of school-aged participants. A balanced design should include equivalent emotion categories and trial frequencies across congruent and incongruent conditions. Larger studies should also use prespecified reaction-time preprocessing rules, standardized task instructions, and controlled testing procedures, together with preregistered primary and exploratory analyses. Such studies could examine whether emotional face–word Stroop performance varies by developmental stage or is associated with academic stress, anxiety, emotion regulation, and student well-being. Overall, the present pilot provides a preliminary behavioral and procedural basis for larger hypothesis-driven research on emotional conflict and attentional processing in developmental, educational, and cross-cultural contexts.

Conclusion

The present pilot study examined reaction-time patterns in six Vietnamese lower secondary school students using an Emotional Face–Word Stroop Task that combined facial expressions with Vietnamese emotion labels. Mean reaction times were longer for incongruent than congruent trials, showing an observed within-sample condition pattern under the present task configuration. Accuracy was descriptively lower for incongruent trials but remained adequate overall. Descriptively, the combination of longer reaction times and lower accuracy in the incongruent condition was not consistent with the conventional pattern expected under a speed–accuracy trade-off.

The exploratory variation across broader stimulus groups should be interpreted as task-specific because the emotion categories and trial frequencies were not equivalent across conditions. The findings therefore provide preliminary behavioral and procedural information for refining a Vietnamese-language emotional face–word Stroop paradigm rather than population-level evidence of stable valence-specific effects. Future studies with larger samples, balanced stimuli, prespecified reaction-time preprocessing procedures, and more controlled testing conditions are needed to evaluate the stability of the observed pattern and extend its use in developmental, educational, and cross-cultural research.

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Conflict of Interests

The authors declare that there is no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon request. Restrictions apply due to privacy considerations related to the small sample of minor participants.

Institutional Review Board Statement

At the time the protocol was reviewed, Ho Chi Minh City University of Education did not operate a separately designated institutional review board or research ethics board. Before data collection, the study protocol underwent prospective institutional review through the university-level research project approval process. A review panel convened by the university and the relevant academic unit evaluated the scientific protocol and the ethical safeguards for research involving minor participants. Following this review, the project was approved on May 10, 2022, under university-level research project code CS.2022.19.24TĐ.

The study procedures were guided by the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and the APA Ethics Code (American Psychological Association, 2017). Written informed consent was obtained from a parent or legal guardian of each participant, and verbal assent was obtained from each participating student before data collection. Participants and their parents or legal guardians were informed about the study procedures, the voluntary nature of participation, confidentiality protections, and the right to withdraw at any time without negative consequences. Recruitment and data collection were conducted independently of any secondary school, and no school records, facilities, or personnel were involved; therefore, permission from a secondary school administration was not applicable.

Author Contributions

Conceptualization, V.L.T.C.; methodology, V.L.T.C. and G.P.T.T.; software, V.L.T.C.; formal analysis, V.L.T.C. and G.P.T.T.; writing—original draft preparation, G.P.T.T.; writing—review and editing, V.L.T.C. All authors have read and agreed to the published version of the manuscript.

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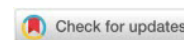
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Impact of Adapted Turkish Pedagogical Training on Practical Competence Development of Biology Teachers: Case of Kazakhstan

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Abstract: The development of practical competence is an important component of biology teacher education, particularly in laboratory, field, and animal-related studies. The aim of this study was to evaluate the effectiveness of adapting selected practice-oriented pedagogical approaches identified during a research internship at Hacettepe University (Turkey) for developing the practical competence of biology students in Kazakhstan. A mixed-methods research design was employed. The Turkish stage included analysis of scientific and methodological literature from the Hacettepe University Library, a structured questionnaire survey of 25 undergraduate students, student interviews, classroom observations and examination of laboratory-, research- and field-oriented teaching practices. These activities, together with the findings of our previous studies, were used to identify instructional elements suitable for adaptation. Selected approaches, including laboratory and experimental learning, applied animal-biology tasks, collaborative learning, digital visualization, virtual laboratories and research-oriented instruction, were integrated with an author-developed electronic learning resource. The adapted approach was tested during a semester-long pedagogical experiment at Abai Kazakh National Pedagogical University involving an experimental group ($n = 42$) and a control group ($n = 35$). The experimental group received practice-oriented instruction, while the control group studied through conventional teaching methods. Subsequently, the developed lesson plans and didactic materials were incorporated into an approved 80-hour professional development course completed by 25 school and university teachers from different regions, who provided feedback on their applicability in real biology teaching practice. The findings support the effectiveness of adapting practice-oriented pedagogical approaches for strengthening practical competence in biology teacher education in Kazakhstan.

Keywords: pedagogical education, biological education, practical competence, practice-based learning, digital technologies, laboratory and field work.

Introduction

Modern pedagogical education is undergoing a paradigm shift from predominantly knowledge-based instruction toward competence-oriented learning models that emphasize practical application, research skills and professional readiness. This transformation reflects global educational trends aimed at aligning academic training with real-world scientific, pedagogical and environmental challenges. In biology education, particularly in teacher training programs, the development of practical competence has become a strategic priority, as it directly influences graduates' ability to apply theoretical knowledge in laboratory, field and classroom contexts.

At the national level, this challenge has been explicitly articulated within Kazakhstan's current educational agenda. In the State Program for the Development of Education and Science of the Republic of Kazakhstan for 2023-2029 ([Government of the Republic of Kazakhstan, 2023](#)), emphasis is placed on strengthening practice-oriented training, digital transformation of higher education and the formation of functional literacy and

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professional competencies among future teachers. The program highlights the need to modernize pedagogical training through laboratory work, applied research and the integration of digital educational technologies.

Furthermore, in his recent Addresses to the Nation, the President of the Republic of Kazakhstan, Kassym-Jomart Tokayev, emphasized that higher education must transcend formal knowledge acquisition and prioritize the preparation of specialists capable of independent decision-making, research activity and practical problem-solving within authentic professional contexts (Tokayev, 2024). Particular attention was devoted to teacher education, where the effectiveness of learning outcomes is intrinsically linked to educators' capacity to translate theoretical knowledge into practice and to effectively integrate modern educational technologies.

In the context of the ongoing Concept for the Development of Higher Education and Science until 2029 and the implementation of the "Digital Kazakhstan" initiative (Government of the Republic of Kazakhstan, 2017), biology education is increasingly viewed as a strategic field for fostering environmental responsibility, scientific thinking and applied competencies. According to national higher education monitoring reports of Kazakhstan, more than 60% of biology-related study programs emphasize theoretical coursework as the dominant mode of instruction, while practical and research-based components remain limited in scope and duration. This is especially relevant for animal-related disciplines, which inherently require observation, experimentation and interaction with real or simulated biological systems.

Despite extensive curricular reforms, a persistent gap remains between theoretical instruction and practical implementation. Survey data from pedagogical universities indicate that approximately 35-40% of students report insufficient opportunities for hands-on laboratory work and field-based activities within biology courses (Ministry of Science and Higher Education of the Republic of Kazakhstan, 2022). Many biology programs in Kazakhstan continue to prioritize content transmission over experiential learning, limiting students' opportunities to engage in experimental research, observation and applied problem-solving. This imbalance is especially critical in the study of animal diversity, where direct observation, laboratory experimentation and fieldwork are fundamental to conceptual understanding and professional competence.

The present study is part of a broader research program initiated in 2023 and focused on the development of practical competence among future biology teachers through practice-oriented biology education. The initial empirical stage was conducted among biology students in Kazakhstan in 2024 and focused on the importance of studying animals in biology for the development of practice-oriented skills (Tolegen and Maimataeva, 2024). Based on these preliminary findings, separate studies were subsequently conducted in which lesson plans were developed using practice-oriented approaches identified during a research internship at Hacettepe University (Turkey). However, the results of the experimental implementation of these approaches in biology education in Kazakhstan are presented in the present study.

Importantly, the term "Turkish pedagogical experience" in this study does not refer to a single standardized national model or to the direct implementation of an entire Turkish curriculum. It specifically refers to a set of practice-oriented instructional principles and teaching methods examined at Hacettepe University through literature analysis, student questionnaires and interviews, classroom observations during biology-related courses and familiarization with laboratory-, research- and field-based teaching practices. Previous studies described these approaches in greater methodological detail, including research- and project-based learning, laboratory and field activities, collaborative learning, virtual and digital visualization tools and reflective assessment (Tolegen et al., 2025). An adapted lesson plan on the topic "Adaptations and Diversity of Vertebrates" was also presented in a previous study (Tolegen and Maimataeva, 2026).

Accordingly, the present study pursued the following interrelated objectives: (1) to summarize the research activities conducted at Hacettepe University; (2) to evaluate the effectiveness of the adapted instructional approach by comparing practical competence and academic performance in the experimental and control groups; and (3) to examine the professional relevance and applicability of the developed methodology and instructional materials through a subsequent professional development course and participant feedback.

Accordingly, the study addressed the following research questions:

RQ₁: What activities conducted during the research at Hacettepe University contributed to the study, and what approaches were suggested by Turkish students for biology teacher education?

RQ₂: Does the adapted practice-oriented teaching approach lead to greater improvements in practical competence and academic performance than traditional instruction?

RQ₃: How do participants in the professional development course evaluate the relevance, applicability, and usefulness of the adapted methodology and instructional materials?

In recent decades, competence-based education has emerged as a dominant paradigm in higher education, particularly in teacher training programs. Unlike traditional knowledge-oriented models, competence-based approaches emphasize the integration of cognitive, procedural and reflective components that enable learners to apply disciplinary knowledge in authentic professional contexts (Mulder, 2014; Ry-chen and Salganik, 2003). Practical competence is thus conceptualized as a multidimensional construct encompassing subject knowledge, practical skills, decision-making ability and professional judgment.

For the purposes of the present study, *practical competence* in biology teacher education is understood as the integrated capacity to apply biological knowledge in authentic or simulated educational and scientific contexts. It comprises four interrelated dimensions: (1) a cognitive dimension, reflected in the understanding and application of biological concepts; (2) a procedural-practical dimension, reflected in the ability to conduct laboratory, observational, experimental, and applied tasks; (3) a research and problem-solving dimension, reflected in the ability to formulate questions, interpret evidence, solve biological problems, and make justified decisions; and (4) a professional-reflective dimension, reflected in the ability to transfer biological knowledge and practical experience to pedagogical situations and evaluate one's own performance. This multidimensional understanding guided the adaptation of the instructional approach and the assessment of practical competence in the Kazakhstani pedagogical experiment.

Within teacher education, practical competence is closely associated with the ability to design learning activities, conduct experiments, interpret data and facilitate inquiry-based learning (Darling-Hammond, 2017). Scholars argue that the development of such competence requires systematic engagement with real or simulated professional tasks rather than passive absorption of theoretical content (Grossman et al., 2009). In biology education, this requirement is particularly pronounced due to the empirical and experimental nature of the discipline.

Research in biology education consistently emphasizes the central role of laboratory work and field-based instruction as essential components of effective learning. In their comprehensive review, Hofstein and Lunetta (2004), drawing on empirical studies conducted in the United States, Israel and several European countries, demonstrated that laboratory-centered instruction contributes to deeper conceptual understanding, enhanced analytical thinking and the development of scientific reasoning, provided that laboratory activities are aligned with clear learning objectives and coherent assessment practices. The authors highlight that studies employing inquiry-oriented laboratory designs reported stronger student engagement in data analysis and interpretation compared to traditional demonstration-based formats.

Empirical evidence is further provided by Domin (2007), who conducted a comparative study at Tennessee State University (USA) involving 17 first-year undergraduate students enrolled in science-related programs. The study contrasted traditional "cookbook" laboratory exercises with problem-based laboratory formats across two consecutive semesters. Survey data and semi-structured interviews revealed that 7 out of 17 students perceived problem-based laboratories as more effective for conceptual understanding and higher-order cognitive skill development, while an additional 7 students reported comparable effectiveness between the two instructional approaches. Despite the limited sample size, the findings indicate the potential of inquiry- and problem-based laboratory instruction to support the development of practical and analytical competencies.

Field-based learning plays a complementary role, particularly in zoology and ecology. Studies by Dillon et al. (2006), conducted by researchers from the United Kingdom in the field of science and environmental education, and Ballantyne and Packer (2009), representing Australian universities and specializing in environmental and outdoor education research, demonstrate that direct interaction with natural environments promotes observational accuracy, ecological literacy and affective engagement with biological content. These experiences support the development of professional competencies relevant to future biology teachers, including environmental awareness and the ability to contextualize theoretical concepts.

Project-based and inquiry-based learning models further strengthen practice-based education by positioning students as active researchers (Hmelo-Silver et al., 2007). In biology teacher education, such approaches have been linked to increased learner autonomy, collaborative skills and sustained motivation (Krajcik and Blumenfeld, 2006). However, empirical studies also indicate that these methods require careful instructional scaffolding and assessment alignment to achieve their intended outcomes.

The rapid digital transformation of education has significantly influenced biology teaching and learning. Virtual laboratories, educational simulations and AR/VR technologies provide alternative means for engaging with complex biological phenomena that may be inaccessible due to safety, cost or ethical

constraints (Makransky and Petersen, 2019). Research indicates that well-designed virtual labs can effectively support conceptual understanding and procedural knowledge, particularly when combined with reflective and inquiry-based tasks (de Jong et al., 2013).

Educational animations and 3D-visualizations have also been shown to enhance spatial understanding and comprehension of dynamic biological processes (Mayer, 2020). In teaching education, digital tools contribute not only to subject learning but also to the development of digital pedagogical competence, which is increasingly recognized as a core professional requirement (Redecker, 2017).

Despite these advantages, several studies caution against the uncritical adoption of technology. Merchant et al. (2014) and Radianti et al. (2020) emphasize that technological effectiveness depends on pedagogical integration, instructional design and alignment with learning objectives. Digital tools that are used as substitutes for traditional lectures without active engagement may have limited impact on competence development.

A recurring issue identified in the literature concerns the assessment of practical competence. While laboratory and field activities are widely implemented, their evaluation often remains fragmented or informal (Bennett et al., 2017). Traditional assessment methods tend to focus on theoretical knowledge rather than practical performance, reflection, or skill integration.

Research in science education underscores the importance of formative and performance-based assessment strategies, including observation protocols, rubrics, portfolios and reflective tasks (Black and William, 2009). However, studies reveal that many teacher education programs lack coherent assessment frameworks that systematically measure practical competence development over time. This gap limits the ability to evaluate the effectiveness of practice-based learning models and to provide targeted feedback to learners.

Although extensive research supports the value of laboratory work, field learning, project- and research-based instruction and digital technologies in biology education, several gaps remain. First, many studies examine these instructional methods separately rather than as components of an integrated practice-oriented approach combining practical activity, research, collaboration, digital resources and reflective assessment. Second, empirical evidence concerning the selective transfer and adaptation of pedagogical practices across different national education systems remains limited.

Furthermore, limited research has examined how internationally informed practice-oriented approaches can be systematically adapted and experimentally evaluated in biology teacher education and subsequently translated into professional development for practicing educators. This gap is particularly relevant to Central Asian educational settings, where empirical research on practice-oriented biology teacher preparation and cross-national methodological adaptation remains limited.

In response to these gaps, the present study builds on previous research conducted within the broader project and examines the experimental implementation of selected practice-oriented pedagogical approaches adapted for biology teacher education in Kazakhstan. The study follows a sequential logic in which exploratory evidence obtained during the Turkish research stage informed the selection of instructional approaches, the adapted methodology was subsequently evaluated through a pedagogical experiment in Kazakhstan and the resulting lesson plans and didactic materials were incorporated into a professional development course for further evaluation by school and university teachers. This design allows the study to examine not only the effectiveness of the adapted approach for developing students' practical competence but also its applicability to biology teaching practice.

Materials and methods

This study employed a mixed research design, combining theoretical analysis and a pedagogical experiment, in order to examine the effectiveness of practice-based approaches in the development of practical competencies among future biology teachers. More specifically, a sequential mixed-methods design was used, combining an exploratory stage, a controlled pedagogical experiment and a subsequent qualitative professional evaluation. The research was conducted in three consecutive stages: (1) research activities at Hacettepe University (Turkey); (2) a semester-long pedagogical experiment at Abai Kazakh National Pedagogical University (Kazakhstan); and (3) evaluation of the developed instructional materials through a professional development course.

The first stage was conducted during a one-month research internship at Hacettepe University (Turkey) in May-June 2025. It included: (1) analysis of scientific and methodological literature available

through Web of Science, Scopus and the Hacettepe University Library; (2) a structured questionnaire survey of 25 undergraduate students (biological faculty); (3) student interviews; (4) non-participant classroom observations; and (5) examination of laboratory-, research- and field-oriented teaching practices.

As part of this stage, a survey-based assessment was conducted among 25 second- and third-year undergraduate students enrolled in full-time biology-related programs within the Department of Science Education at Hacettepe University. The participants had a mean age of approximately 20 years. Data were collected using a structured questionnaire designed to examine students' perceptions of the teaching methods and practical approaches used by their instructors, including their perceived effectiveness, accessibility, and usefulness for learning. The findings provided a student-centered perspective for selecting approaches for subsequent adaptation and testing among Kazakhstani university students of a comparable age group. The questionnaire included items addressing the following aspects:

- contexts of biological knowledge acquisition (school, university, extracurricular activities);
- instructional methods used in biology education (laboratory work, experimental research, field activities, visual and animated materials, theoretical instruction);
- perceived impact of biology courses on professional skill development;
- the role of the teacher in organizing and supporting practical learning;
- use of digital and innovative technologies (virtual laboratories, animations, mobile applications, AR/VR);
- assessment methods applied in practical classes;
- effectiveness of learning animal-related topics and applicability of acquired knowledge;
- opportunities for studying animal behavior;
- organizational challenges in practical biology education;
- students' perceptions of the most effective methods for enhancing practical competence.

The questionnaire items were aligned with the objectives of the study and informed by previous empirical research in science education. Responses were recorded mainly in categorical and multiple-choice formats and subsequently analyzed using descriptive statistics.

Student interviews provided additional information about students' learning experiences, the relationship between theoretical and practical instruction, and their perceptions of the teaching approaches used during their studies. Non-participant classroom observations were conducted through attendance at biology-related classes taught by university professors. The observations were used to examine how teaching and practical activities were organized and how different instructional approaches were implemented during actual university classes. In addition, familiarization with the available laboratory, research, and field-based teaching resources provided further information on the organization of practical biology education at the university.

The evidence obtained from the literature analysis, student questionnaire and interviews, classroom observations, and examination of teaching practices was considered collectively when selecting instructional elements for adaptation and subsequent experimental implementation in Kazakhstan.

The pedagogical experiment was conducted in Kazakhstan with 77 students majoring in biology education at Abai Kazakh National Pedagogical University. The participants were divided into an experimental group ($n = 42$) and a control group ($n = 35$):

- the experimental group (EG) ($n = 42$), which was taught using adapted practice-oriented teaching methods and instructional materials developed during the preceding stages of the research, including laboratory work, digital tools and applied tasks;
- the control group (CG) ($n = 35$), which continued learning according to the traditional curriculum without the additional pedagogical intervention.

The experimental instruction was implemented over the course of one academic semester within regular university classes. Group allocation was based on existing academic group structures to ensure natural learning conditions. The experimental instruction focused on:

- laboratory-based and experimental learning activities;
- applied tasks related to animal biology;
- integration of digital tools, including visual materials and virtual laboratories;
- development of practical skills, research abilities and professional preparedness.

Academic performance and practical competence development were evaluated through comparative analysis of learning outcomes between the experimental and control groups.

Following the pedagogical experiment, the developed lesson plans and didactic materials were incorporated into the professional development course entitled "Development of Pedagogical Competencies of Biology Teachers", which was officially approved for implementation in Kazakhstan. The course was designed to support the practical application of the developed methodology and to obtain professional feedback on its relevance and applicability in biology teaching.

The professional development course involved 25 participants, primarily experienced school and university teachers from different regions of Kazakhstan, with a small number of future biology teachers. The training program comprised 80 academic hours, including 40 hours of online instruction and 40 hours of independent learner-centered study. The online sessions were delivered via the Zoom platform. All 25 participants completed the course.

The training course consisted of a series of lectures, master classes and interactive sessions integrating theoretical and practical components. The theoretical modules addressed the following topics:

- theoretical and methodological foundations of practical competence formation;
- methodology for organizing practice-oriented learning in biology education;
- educational technologies aimed at developing practical competencies;
- assessment of practical competence and methodological experience (variable module).

The practical component of the course included virtual laboratory activities, animated and visual materials for studying animal biology, and project-based collaborative tasks focused on solving authentic pedagogical and professional problems. The developed lesson plans and didactic materials were incorporated into these activities to allow participants to examine their potential application in biology teaching practice. The instructional sessions concluded with guided reflective discussions aimed at supporting pedagogical reflection and the practical application of the course materials. The course also included elements aimed at developing communicative skills, self-reflection and environmental competence.

Qualitative data were collected through semi-structured interviews and reflective feedback sessions conducted online. Expert evaluation focused on:

- changes in practical competence;
- effectiveness of teaching animal-related topics;
- clarity and applicability of adapted instructional methods;
- relevance of digital and virtual laboratory tools in biology education.

All participants were fully informed about the objectives and procedures of the study prior to data collection. Participation was voluntary and written informed consent was obtained from all respondents. Anonymity was strictly maintained throughout the research process. All collected data were processed and stored in aggregated form, without the use of personal identifiers, ensuring compliance with ethical standards for educational research.

Results

Results of the Turkish Research Stage. The data obtained from the survey conducted among 25 undergraduate biology students in Turkey were analyzed using descriptive statistical methods, including frequency counts and percentage distributions. This analysis was used to identify patterns in students' experiences of biology instruction and their perceptions of practice-oriented learning and practical competence development.

Analysis of responses to the question "Where and how did you learn biology?" demonstrated that the majority of respondents (72%) continued acquiring biological knowledge primarily at the university level, while 28% identified school education as their main source of knowledge. None of the respondents reported participation in extracurricular academic activities such as additional courses, conferences or competitions, highlighting the central role of formal higher education in professional competence development. This finding indicates that the university represented the principal educational environment for the continued development of biological knowledge among the surveyed students.

With regard to instructional methods used in biology education, the data revealed a strong em-

phasis on practice-oriented approaches. Laboratory practices were reported by 80% of respondents, experimental laboratory work by 68%, and the use of visual and animated learning materials by 76%. At the same time, 28% of students indicated that instruction was often limited to theoretical explanations and 12% reported reliance exclusively on textbooks. Overall, these findings demonstrate that laboratory, experimental and visual forms of instruction were strongly represented in the students' university learning experience alongside theoretical teaching.

The perceived impact of biology courses on professional skill development varied among respondents. While 44% reported a strong positive influence and 40% indicated a moderate effect, 16% stated that biology education had no noticeable impact on their professional skills. Thus, 84% of respondents perceived biology education as contributing to their professional skill development to a strong or moderate degree.

Analysis of the teacher's role showed that 48% of students experienced active pedagogical guidance and support, whereas 40% reported sufficient but unsystematic assistance. A smaller proportion (12%) indicated predominantly independent learning. No respondents reported a complete absence of instructional support.

The use of digital and innovative technologies was also examined. Video lectures and AR/VR technologies were reported by 60% of respondents, educational animation programs by 44% and mobile applications by 24%. Virtual laboratories were used by only 16% of students. The findings therefore demonstrate the presence of diverse digital and visualization tools in biology instruction, although the frequency of their use differed across technologies.

Assessment practices following practical classes were characterized by fragmentation. Observation-based assessment was reported by 40% of respondents, competency-based criteria by 20% and self- and peer-assessment by 8%. Notably, 20% of students indicated that no formal assessment was conducted. The results show that practical learning was accompanied by different forms of assessment, with observation-based assessment being the most frequently reported approach.

Regarding the study of animal-related topics, only slightly more than half of respondents reported effective knowledge acquisition. Laboratory-based learning (20%) and experimental research (16%) were identified as the most effective learning modes. The practical applicability of acquired knowledge was most frequently evaluated as moderate (52%), while 20% of respondents rated it as low. These findings further indicate the relevance of practical and experimental activities for learning animal-related biological content.

Overall, the Turkish survey demonstrated a substantial practice-oriented component in the biology education experienced by the participating students. Laboratory work, experimental activities, visual and digital resources, and teacher guidance were consistently represented in their responses, while 84% perceived biology education as making a strong or moderate contribution to their professional skill development. Together with the interviews, classroom observations and examination of laboratory-, research- and field-oriented teaching practices, these findings provided empirical support for selecting instructional elements for subsequent adaptation to biology teacher education in Kazakhstan.

The survey results provided an overall indication of practical competence development among biology students in Turkey. The distribution of practical competence levels based on students' self-assessment is summarized in Table 1.

Table 1. Results of practical competence indicators among biology students in Turkey (n = 25)

Level of practical competence	Number of students	Percentage (%)
High	11	44.0
Average	10	40.0
Low	4	16.0

The results demonstrate that at the initial stage of the study, the majority of Turkish students showed moderate and high levels of practical competence, primarily associated with laboratory practices, experimental work and the use of visual and digital materials. However, 16% of students showed a low level of practical competence, indicating differences in practical competence development among the respondents.

Further analysis of instructional methods revealed that 80% of respondents participated in laboratory practices and 76% used visual or animated materials, whereas 28% reported that instruction also included predominantly theoretical explanations. These findings demonstrate the strong presence of practice-oriented methods alongside theoretical instruction in the biology education of the surveyed students.

Results of the Pedagogical Experiment in Kazakhstan. The findings of the preceding stages and our previous comparative study indicated that practice-oriented, research-based and digital approaches were more strongly represented in the learning experiences examined at Hacettepe University, whereas the earlier Kazakhstani data showed a greater reliance on theoretical instruction. The previous study also proposed an adapted methodological framework combining inquiry-based learning, laboratory and digital activities, collaborative tasks and reflective assessment. These findings informed the instructional methods and materials subsequently tested in the present pedagogical experiment.

More specifically, five elements of the Turkish practice-oriented approach were adapted for the pedagogical experiment in Kazakhstan. Project-based learning was transformed into small-group research tasks in which students investigated selected topics related to animal diversity. The use of digital zoological tools was adapted through virtual laboratory activities, AR/VR resources and 3D-animal models for observing anatomical structures and biological adaptations. Field-oriented learning was modified into locally feasible biodiversity observation tasks, allowing students to collect and analyze biological information without requiring extended field practice. The student-centered approach was implemented by assigning students the roles of researchers and presenters who analyzed observations, interpreted results and discussed their findings in groups. Finally, reflection-based assessment was incorporated through self-evaluation and structured feedback alongside conventional assessment. These adapted components were integrated into regular biology instruction to develop practical, research, digital and communicative competencies.

To assess the effectiveness of the adapted practice-oriented instructional approach, the outcomes of the experimental group (EG, $n = 42$) and the control group (CG, $n = 35$) were compared. Changes in the overall practical competence indicator in both groups are presented in Table 2.

Table 2. Dynamics of practical competence in the experimental and control groups

Group	Pre-experimental stage (%)	Post-experimental stage (%)	Change (percentage points)
Experimental group	46.2	89.5	+43.3
Control group	33.6	47.6	+14.0

At the pre-experimental stage, the practical competence indicator was 46.2% in the experimental group and 33.6% in the control group. At the post-experimental stage, the indicator increased to 89.5% in the experimental group and to 47.6% in the control group. Thus, the experimental group demonstrated an increase of 43.3 percentage points, compared with an increase of 14.0 percentage points in the control group. The increase observed in the experimental group was therefore more than three times greater than that recorded in the control group. This pattern suggests that systematic integration of practical tasks, research-oriented activities, digital resources and collaborative learning provided students with substantially more opportunities to apply biological knowledge in practice.

An independent samples t-test confirmed a statistically significant difference in practical competence between the experimental and control groups at the post-experimental stage ($t = 5.41$, $p < .01$). The corresponding effect size (Cohen's $d \approx 1.24$) indicated a large effect in favor of the experimental group, supporting the practical significance of the observed difference.

Changes in academic performance in pedagogical disciplines among undergraduate students were also analyzed. The distribution of academic achievement levels at the pre- and post-experimental stages is presented in Table 3.

Table 3. Dynamics of academic performance in experimental and control groups

Academic achievement level	EG – pre-experimental stage (%)	EG – post-experimental stage (%)	CG – post-experimental stage (%)
High (90-100 points)	19.0	33.4	20.0
Average (70-89 points)	54.8	47.6	54.3
Low (below 69 points)	26.2	19.0	25.7

The results show that in the experimental group, the proportion of students with a high level of academic achievement increased from 19.0% to 33.3% (+14.3 percentage points), while the proportion of students with low academic achievement decreased from 26.2% to 19.0%. At the post-experimental stage, 33.3% of students in the experimental group demonstrated high academic achievement compared with 20.0% in the control group, while low academic achievement was observed in 19.0% and 25.7% of students, respectively.

An independent samples t-test confirmed a statistically significant difference in academic performance between the experimental and control groups at the post-experimental stage ($t = 4.18$, $p < .01$). The corresponding effect size (Cohen's $d \approx 0.96$) indicated a large effect in favor of the experimental group. These findings indicate that the practice-oriented instructional approach was associated not only with greater development of practical competence but also with improved academic performance. Taken together, the quantitative findings suggest that the combination of research-oriented tasks, practical activities, digital learning resources and collaborative forms of work was associated with stronger outcomes than conventional instruction alone.

Results of the Professional Development Course. To complement the quantitative results, a qualitative evaluation was conducted during the third stage of the study. This stage involved 25 participants, primarily experienced school and university teachers from different regions of Kazakhstan, with a small number of future biology teachers, who completed the professional development course based on the developed methodology and instructional materials.

Qualitative feedback was collected through semi-structured interviews and reflective discussions focusing on the clarity, accessibility and pedagogical effectiveness of teaching animal-related topics using virtual laboratories, animated materials and practice-oriented instructional tasks. Participants' responses indicated improved instructional clarity, stronger integration of theory and practice and the practical applicability of digital tools in biology teaching.

The feedback provided additional evidence of the educational relevance and practical applicability of the developed methodology and instructional materials. Together with the quantitative findings of the pedagogical experiment, these results provided a broader evaluation of the practice-oriented approach in biology teacher education. All statistical analyses were conducted using Statistica 7.0 software.

Overall, the findings from the three stages of the study provide consistent evidence supporting the adapted practice-oriented approach. The Turkish research stage identified practice-oriented instructional elements suitable for adaptation, while the pedagogical experiment in Kazakhstan demonstrated significant improvements in practical competence and academic performance among students in the experimental group. The subsequent professional development course further confirmed the relevance and practical applicability of the developed methodology and instructional materials. Taken together, these findings provide a coherent empirical basis for evaluating the effectiveness and applicability of the adapted approach in biology teacher education.

Discussions

The findings from the Turkish stage of the study confirm that practice-oriented instructional methods, particularly laboratory activities, experimental research and the use of visual and digital materials, play a crucial role in the development of students' practical competencies. Similar conclusions have been drawn in international studies emphasizing that laboratory-based and inquiry-oriented biology education enhances conceptual understanding, procedural knowledge and professional readiness (Hofstein and Lunetta, 2004; Dillon et al., 2006). However, the presence of students who reported predominantly theoretical instruction highlights a persistent gap between practice-oriented and theoretical components of biology education.

The results also indicate that digital technologies, including AR/VR tools and educational animations, are integrated into biology education, yet their application remains fragmented across different types of digital resources. This observation aligns with the findings of Merchant et al. (2014) and Makransky and Petersen (2019), who argue that digital tools contribute significantly to learning outcomes only when embedded within a coherent pedagogical framework. The Turkish data therefore served not merely as a descriptive baseline but as a methodological reference point for selecting and adapting practice-oriented instructional approaches for Kazakhstan.

The pedagogical experiment conducted in Kazakhstan demonstrated that the adapted practice-oriented instructional approach led to significant improvements in both practical competence and academic performance among students in the experimental group. These results are consistent with research emphasizing that teacher education programs integrating experiential learning, reflective practice and digital tools are more effective in fostering professional competencies (Darling-Hammond et al., 2017). The large effect observed in practical competence development suggests that the adapted practice-oriented approach was not only statistically effective but also educationally meaningful.

An important contribution of the implemented professional development course lies in its methodological structure, which combined theoretical grounding, virtual laboratory work, project-based tasks and reflective discussions. This integrated approach corresponds with the principles of practice-based learning and supports previous studies highlighting the role of reflection and contextualized practice in teacher competence development (Loughran, 2013). Moreover, the inclusion of elements aimed at developing communicative skills and self-reflection aligns with contemporary views on holistic teacher competence, which extends beyond subject knowledge alone.

Despite these positive outcomes, several limitations should be acknowledged. The study was conducted within a limited sample size and relied on a case-based design, which may restrict the generalizability of the findings. In addition, the semester-long duration of the pedagogical experiment did not allow for assessing long-term effects on professional practice. Similar methodological constraints have been noted in comparable studies on teacher professional development (Opfer and Pedder, 2011). Future research should therefore adopt longitudinal designs and involve a broader range of institutions and regions to strengthen external validity.

Overall, the discussion of results demonstrates that adapting selected Turkish practice-oriented biology education approaches to the Kazakhstani context is both feasible and effective when aligned with local educational conditions and pedagogical priorities. The study contributes to the growing body of international research emphasizing the importance of cross-cultural transfer of educational innovations grounded in methodological adaptation rather than direct replication.

Conclusions

In conclusion, the findings of this study demonstrate that selected practice-oriented pedagogical approaches identified during the research stage at Hacettepe University can be effectively adapted to biology teacher education in Kazakhstan. The integration of laboratory and experimental activities applied animal-biology tasks, digital and virtual resources, collaborative learning and research-oriented instruction contributed to significantly greater development of students' practical competence and academic performance compared with conventional instruction. The professional development stage further confirmed the relevance and practical applicability of the developed methodology and instructional materials for biology teaching.

Based on these findings, biology teacher education programs are recommended to strengthen the systematic integration of laboratory and experimental work, research-oriented and collaborative tasks, virtual laboratories, digital visualization and applied activities related to animal biology. The developed instructional materials may also be incorporated into professional development programs for practicing biology teachers to support the transfer of practice-oriented methods into classroom teaching.

Further implementation of the adapted approach in different universities and regions of Kazakhstan is recommended to evaluate its effectiveness across broader educational settings. Future research should involve larger samples and longer intervention periods to examine the sustainability of practical competence development and the long-term effects of the proposed methodology on teachers' professional practice.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

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Author Contributions

Conceptualization, Tolegen A.A., Maimataeva A.D. and Erten S.; methodology, Tolegen A.A.; software, Tolegen A.A.; formal analysis, Tolegen A.A., Maimataeva A.D. and Erten S.; writing—original draft preparation, Tolegen A.A.; writing—review and editing, Erten S. and Maimataeva A.D. All authors have read and agreed to the published version of the manuscript.

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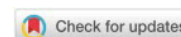
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Representational Difficulty Across Cognitive Stages in Quadratic Functions: An APOS–Newman Analysis

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Abstract: This study aims to identify the types of students' mathematical representation errors using Newman's error classification and to analyze their relationships with the stages of cognitive development in the Action, Process, Object, and Schema theory. The study employed a qualitative descriptive approach involving 42 tenth-grade students from a senior high school. Data were collected through a mathematical representation ability test and in-depth interviews, and were analyzed qualitatively by mapping the types of errors and students' cognitive development stages. The results indicate that students' mathematical representation ability remains low, with symbolic representation the most challenging aspect across all ability levels. Comprehension and transformation errors were dominant among low-ability students, most of whom were at the Action stage. Moderate-ability students showed an emerging uneven pattern of cognitive attainment, with Schema-level attainment in the visual representation and, to a limited extent, in the verbal representation, whereas no Schema attainment was observed in the symbolic representation. Meanwhile, high-ability students demonstrated Schema-level attainment in the visual and verbal representations, whereas their symbolic performance remained at the Object stage because of persistent process-skill difficulties. These findings indicate that cognitive development is specific to the type of representation and does not occur uniformly across representations. This pattern of uneven cognitive attainment across representational forms is conceptualized in this study as asymmetrical representational development. The implications of this study suggest that the teaching of quadratic functions should emphasize coordination among visual, symbolic, and contextual representations through multi-representation approaches and gradual scaffolding to consistently support students' conceptual understanding.

Keywords: mathematical representation, quadratic function, APOS, Newman error analysis, cognitive stages, asymmetrical representational development.

Introduction

Mathematical representation ability constitutes a fundamental foundation in the construction of mathematical knowledge, as it enables students to coordinate symbolic expressions, visual structures, and contextual interpretations within a coherent conceptual system. From a cognitive perspective, mathematical processes invariably involve transformations across representations (Mainali, 2021). The involvement of multiple representational transformations suggests that conceptual understanding is constructed not only through procedural mastery but also through the ability to transform and integrate multiple systems of representation flexibly. The ability to transition from intuitive or visual representations to formal, analytical reasoning is an essential component in developing a more structured mathematical understanding (Santos-Trigo, 2024).

One mathematical topic that requires flexibility in representational ability is quadratic functions. A comprehensive understanding of quadratic functions requires the ability to transform symbolic expressions into graphical and other forms of representation (Tiew, Hoon, Singh, Walida, and Faradiba, 2023).

However, transforming between representations in the context of quadratic functions imposes a high

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cognitive load. Various studies indicate that students' difficulties do not always originate solely from procedural errors, but are related to obstacles in constructing and interpreting representations, particularly graphical representations derived from the symbolic form of quadratic functions (Luthfiani et al., 2025; Rahmawati et al., 2025; Wilkie, 2024).

Several previous studies have focused on identifying the types and frequencies of students' errors in solving quadratic function problems by employing error classifications such as Newman Error Analysis or categories of procedural and conceptual errors (Pramesti, Shoffa, and Soemantri, 2024; Rahman and Foad, 2021).

The Newman framework is primarily descriptive in identifying the location of errors and does not fully explain the cognitive and metacognitive mechanisms underlying them. In fact, transitions between representations require processes of exploration, meaning-making, and regulation of thinking that do not occur automatically (Faradiba, Sa'dijah, Parta, and Rahardjo, 2019; Fathonah, Cahyono, Haryani, Sarwi, and Lestari, 2024). These considerations suggest that error analysis alone is insufficient to understand students' thinking dynamics comprehensively.

APOS theory (Action, Process, Object, Schema), originally developed by Dubinsky, provides a cognitive framework for understanding how mathematical concepts are gradually constructed within students' mental structures. The action stage represents procedural activities that remain mechanical in nature; the process stage indicates the internalization of actions into mental operations; the object stage marks the ability to treat a process as a conceptual entity; and the schema stage reflects the organized integration of various conceptual objects within a more complex system of thought. APOS theory views mathematics learning as a process that proceeds through mechanisms of interiorization, coordination, and encapsulation until an organized conceptual schema is formed (Bintoro, Sukestiyarno, Mulyono, and Walid, 2021; Selden and Vidakovic, 2022; Sopamena, Kaliy, Sehuwaky, Kasliyanto, and Juhaevah, 2021).

Although APOS theory has been widely used to analyze students' mathematical understanding, most of these studies focus on characterizing conceptual structures and levels of understanding (Şefik, Uzun, and Dost, 2021). Empirical exploration of how representational errors develop as students transition from the action stage to the schema stage remains relatively limited, particularly in the context of quadratic functions. The integration of Newman's classification and APOS theory has the potential to provide a deeper understanding of students' representational errors. Through this integration, errors are no longer viewed merely as procedural mistakes, but as indicators of obstacles in understanding relationships among concepts and in coordinating different forms of representation.

Based on this framework, this study aims to identify the types of students' mathematical representation errors in quadratic function material using Newman's classification and to analyze how these errors relate to the stages of cognitive development in APOS theory. By linking students' error analysis with a cognitive development framework, this study seeks to explain how and why representational errors emerge and develop. Furthermore, the findings of this study are expected to assist teachers in designing learning activities that are more aligned with students' ways of thinking and their cognitive needs.

Materials and methods

This study employed a qualitative descriptive approach to analyze why students make errors in completing a mathematical representation ability test using the APOS theoretical framework. The approach was selected to provide an in-depth understanding of students' cognitive processes, particularly in revealing the stages of thinking that lead to errors based on the framework of Action, Process, Object, and Schema (APOS). Thus, this study aims not only to identify the types of errors students make but also to understand how their mental structures are formed when solving mathematical representation problems.

This study involved 42 tenth-grade students from one senior high school in the city of Pekanbaru as the research subjects. The school is a public educational institution that implements the Merdeka Curriculum and has taught quadratic functions. The criteria for students who became research subjects were that they had studied quadratic functions. The students participated voluntarily and provided written consent.

The implementation of this study was carried out through several main stages. The first stage was the preparation of research instruments, namely the development of mathematical representation ability test items that included three types of representation ability indicators, namely visual, symbolic, and ver-

bal. These items then underwent an expert validation process to ensure the suitability of the content with the representation ability indicators being measured. After the validation process, the items were revised according to the suggestions from the validators, followed by a pilot test with a group of students outside the research sample to examine validity and reliability.

The second stage was administering the test to the research subjects. The test was given to 42 tenth-grade students at one senior high school in the city of Pekanbaru. Students were asked to solve the three representation problems independently within the allotted time. All student responses were collected for further analysis.

The third stage was scoring and grouping students by ability level. Each student's response was assessed against the preprepared scoring criteria. The obtained scores were then used to classify students into high, moderate, or low ability categories, using the mean and standard deviation as reference points. The criteria for grouping students' abilities are shown in the following table.

Table 1. *Criteria for grouping students' ability*

Score	Category
score < 3	Low
$3 \leq \text{score} \leq 21$	Moderate
score > 21	High

The fourth stage was the analysis of students' errors. Students' responses, which had been grouped, were analyzed to identify error types using the Newman error categories. The types of Newman errors used in this study included comprehension error, transformation error, process skill error, and encoding error. The description of error types and their indicators was carried out by modifying the criteria proposed by [Siregar and Solfitri \(2019\)](#) and adapting them to responses from the mathematical representation ability test on the quadratic function material.

Table 2. *Criteria for types of student errors using Newman theory*

No	Type of Error	Indicators
1	Comprehension	Leaving the answer blank
		Unable to identify the information required to answer the question
		Copying the question without continuing the solution
2	Transformation	Using an incorrect method in solve the problem
		Not transforming the information obtained in the problem into a form of representation that can solve the problem.
		Attempting to transform the information into a representation form, but errors occur in the representation provided
3	Process Skill	Making calculation errors
		Providing a problem-solving procedure but not completing it
		Providing a complete problem-solving procedure, but errors occur in the concept used
4	Encoding	Errors occur in writing mathematical symbols or notation
		Not writing the final answer
		Errors occur in writing the final answer

For verbal responses classified as encoding errors, interview data were used to further examine the source of the error. In cases where students obtained a mathematically correct result but were unable to express its meaning in the context of the problem, the underlying difficulty was interpreted as involving semantic translation or contextual mapping rather than notational production.

The fifth stage was the analysis of the APOS stages. At this stage, students' responses were also analyzed according to the Action, Process, Object, and Schema stages to determine which thinking stages had or had not been formed in each ability group. In this study, the criteria for grouping students' thinking stages based on APOS theory were developed by modifying those proposed by [Yarman, Dwina, Murni, Yerizon, and Hevardani \(2024\)](#) and adapting them to the quadratic function test instrument.

Table 3. Criteria for students' thinking stages based on APOS theory

No	APOS stage	Indicators
1	Action	Reading the given problem Identifying the information given in the problem and what is being asked Performing calculation operations in the steps of solving the problem Determining relevant coordinate points from the given quadratic function graph
2	Process	Determining the characteristics of a quadratic function Determining the vertex of a quadratic function using the formula Determining the y-intercept Determining the coordinate points passed by the quadratic function graph using substitution Drawing the quadratic function graph correctly based on the coordinate points given in the problem
3	Object	Drawing the graph accurately by considering the characteristics of the quadratic function graph Determining the value of coefficient b using the equation of the axis of symmetry Formulating the quadratic function equation Determining the maximum point of the quadratic function
4	Schema	Using the results of calculations (such as the vertex, roots, and graph) to understand the context of the problem given in the question Recognizing number patterns in the values of the quadratic function for various inputs Relating the maximum or minimum value of a quadratic function to practical applications in economic problems

The sixth stage was conducting interviews. To support the validity of the analysis results, unstructured interviews were conducted with students from each ability category: high, moderate, and low. The interviews aimed to explore more deeply the students' thinking processes when solving the problems, which were among the causes of the errors.

The final stage was data analysis and interpretation. Data from the tests and interviews were analyzed qualitatively to obtain a comprehensive description of the causes of students' errors in solving mathematical representation problems and their relationship with the stages of thinking in APOS theory.

Research data were collected through test and non-test techniques. The test technique involved administering a mathematical representation ability test. The mathematical representation ability test used included three indicators: visual, symbolic, and verbal. The non-test technique was conducted through interviews. The instrument used was an unstructured interview guide. The interview aimed to explore in greater depth the stages of students' thinking in solving representation problems, as well as to determine the reasons for these errors.

Data analysis was conducted in several stages. First, all student test responses were analyzed to identify errors based on the Newman categories. Data on the number of students who made each type of error were recorded and compared across ability categories.

Second, based on APOS theory, student responses were mapped to determine the stages achieved, starting with the action, process, and object stages, and progressing to the schema stage. These data were then compiled to observe the patterns of APOS stage achievement in each ability group and for each type of error.

Furthermore, interview data were analyzed to identify patterns of cognitive difficulties, misconceptions, and representational obstacles experienced by students. The results of this analysis were then triangulated with findings from the written tests to increase data credibility.

The validity of the data in this study refers to the trustworthiness criteria proposed by Lincoln and Guba, including credibility, transferability, dependability, and confirmability (Korstjens and Moser, 2018; Stahl and King, 2020). In this study, credibility was ensured through instrument validation by three mathematics education experts and method triangulation between written tests and interviews. Interviews were also used for member checking to ensure that the researcher's interpretation corresponded to the students' thinking. Transferability was addressed by providing descriptions of the school, student characteristics, and test material. Dependability was ensured through systematic documentation of the entire

research process, forming an audit trail. Confirmability was conducted through validation of the analysis results by two mathematics teachers to ensure that the classification of strategies and errors was objective and consistent with classroom practice. The two teachers were not directly involved in the analysis, allowing them to provide independent judgments regarding the objectivity of the findings.

Results

The test results show that the average score for students' mathematical representation ability was 11.02 (26.89%), indicating that students' representation ability was still in the low category overall. Of the 42 students who became research subjects, 6 were categorized as the low-ability group, 27 as the moderate group, and 9 as the high-ability group.

Table 4. *Distribution of Students' Correct and Incorrect Answers*

Answer	Ability	Category					
		Visual		Symbolic		Verbal	
		n	%	n	%	n	%
Correct	Low	0	0	0	0	0	0
	Moderate	11	40.74	0	0	1	3.70
	High	1	11.11	0	0	5	55.56
Incorrect	Low	6	100	6	100	6	100
	Moderate	16	59.26	27	100	26	96.30
	High	8	88.89	9	100	4	44.44

Based on Table 4, which presents the representation indicators (visual, symbolic, and verbal), the symbolic indicator has the lowest success rate. This finding indicates that algebraic modeling and symbolic manipulation are the main challenges in understanding quadratic functions.

The analysis of errors based on Newman's classification for each representation indicator reveals distinct patterns for each representation type. The distribution is shown in Table 5 below.

Table 5. *Distribution of students' errors based on Newman classification*

Ability	Error Type	Category					
		Visual		Symbolic		Verbal	
		n	%	n	%	n	%
Low	Comprehension	4	66.67	1	16.67	5	83.33
	Transformation	1	16.67	5	83.33	1	16.67
	Process Skill	1	16.67	0	0	0	0
	Encoding	0	0	0	0	0	0
Moderate	Comprehension	6	22.22	7	25.93	8	29.63
	Transformation	4	14.81	10	37.04	12	44.44
	Process Skill	3	11.11	10	37.04	5	18.52
	Encoding	3	11.11	0	0	1	3.70
High	Comprehension	0	0	0	0	0	0
	Transformation	4	44.44	0	0	0	0
	Process Skill	3	33.33	9	100	1	11.11
	Encoding	1	11.11	0	0	3	33.33

For the visual indicator, students were asked to draw the graph of a quadratic function based on the provided verbal information. In this indicator, the difficulties of the low-ability group were dominated by difficulties in understanding and identifying the information needed to draw the graph (comprehension error). The moderate group showed a combination of comprehension and transformation errors, while the

high-ability group experienced more transformation and process-skill errors in connecting verbal information to graphical representations.

Next, in the symbolic indicator, students were asked to construct the quadratic function formula based on information presented in the form of an image. This task required students to transform a visual representation into a symbolic form while performing appropriate algebraic manipulations. In general, errors in the symbolic indicator were concentrated at the transformation and process skill stages, although the distribution varied across ability levels.

In the low-ability group, most errors occurred at the transformation stage. Students were unable to convert the information contained in the image into an appropriate mathematical model. In the moderate-ability group, errors were distributed across two main categories: transformation and process skills. Students generally understood what needed to be done but experienced difficulties in constructing the function model accurately and performing algebraic calculations consistently. In the high-ability group, errors occurred more frequently at the process skill stage. Students generally succeeded in performing representation transformations correctly, but still made mistakes in calculation processes or in applying algebraic procedures. These errors indicate that at the high-ability level, obstacles no longer lie in understanding or transforming representations, but in the accuracy and consistency of symbolic manipulation.

In the verbal indicator, which tested students' understanding of the meaning of the vertex of a quadratic function in a real-world context, the low-ability group again showed dominance of comprehension errors, particularly in interpreting contextual information. Errors at the moderate-ability level mostly occurred at the transformation and process skill stages. They often experienced difficulties in converting problem information into mathematical form that could be solved and in applying problem-solving procedures correctly. Meanwhile, in the high-ability group, errors occurred more frequently at the encoding stage. Interview evidence indicated that, in some cases, students produced numerically correct results but were unable to express them in the contextual meaning required by the problem. These cases were interpreted as difficulties in semantic translation or contextual mapping rather than notational production.

Mapping the errors to the APOS stages shows a relatively consistent pattern of cognitive development. The distribution of errors by APOS stage for each indicator is shown in Tables 6, 7, and 8 below.

Table 6. *Distribution of APOS stages in visual problems*

Ability	Error type	Category							
		Action		Process		Object		Schema	
		n	%	n	%	n	%	n	%
Low	Comprehension	4	66.67	0	0	0	0	0	0
	Transformation	1	16.67	0	0	0	0	0	0
	Process Skill	0	0	1	16.67	0	0	0	0
Moderate	Comprehension	6	22.22	0	0	0	0	0	0
	Transformation	3	11.11	1	3.70	0	0	0	0
	Process Skill	0	0	2	7.41	1	3.7	0	0
	Encoding	0	0	0	0	3	11.11	0	0
High	Comprehension	0	0	0	0	0	0	0	0
	Transformation	2	22.22	2	22.22	0	0	0	0
	Process Skill	0	0	3	33.33	0	0	0	0
	Encoding	0	0	0	0	1	11.11	0	0

Table 7. Distribution of APOS stages in symbolic problems

Ability	Error type	Category							
		Action		Process		Object		Schema	
		n	%	n	%	n	%	n	%
Low	Comprehension	1	16.67	0	0	0	0	0	0
	Transformation	5	83.33	0	0	0	0	0	0
Moderate	Comprehension	7	25.93	0	0	0	0	0	0
	Transformation	10	37.04	0	0	0	0	0	0
	Process Skill	0	0	5	18.52	5	18.52	0	0
High	Process Skill	0	0	0	0	9	100	0	0

Table 8. Distribution of APOS stages in verbal problems

Ability	Error type	Category							
		Action		Process		Object		Schema	
		n	%	n	%	n	%	n	%
Low	Comprehension	5	83.33	0	0	0	0	0	0
	Transformation	1	16.67	0	0	0	0	0	0
Moderate	Comprehension	8	29.63	0	0	0	0	0	0
	Transformation	12	44.44	0	0	0	0	0	0
	Process Skill	0	0	2	7.41	3	11.11	0	0
	Encoding	0	0	0	0	1	3.70	0	0
High	Process Skill	0	0	1	11.11	0	0	0	0
	Encoding	0	0	0	0	1	11.11	2	22.22

To make the asymmetry between representation types explicit, Table 9 synthesizes the highest APOS stage attained by each ability group across the visual, symbolic, and verbal indicators, drawing on both the error-level mapping in Tables 6–8 and the correct-response data in Table 4. In constructing this synthesis, correct and complete responses were treated as evidence of Schema attainment, while erroneous responses were mapped to the highest APOS stage evidenced in the response; the full Newman error distributions are reported in Table 5, while their APOS-stage mappings are presented in Tables 6–8.

Table 9. Cross-Representational Synthesis of APOS Attainment Across Ability Groups

Ability	Visual	Symbolic	Verbal	Interpretation
Low	Action–Process; no Schema attained (comprehension dominant, n=4, 66.67%; no correct responses)	Action only; no Schema attained (transformation dominant, n=5, 83.33%; no correct responses)	Action only; no Schema attained (comprehension dominant, n=5, 83.33%; no correct responses)	Cognitive construction remained predominantly confined to the Action stage across representations, with only limited progression to Process in the visual representation and no Schema attainment observed.
Moderate	Schema attained (n=11, 40.74% correct); errors otherwise reached Object (n=4, 14.81%)	Action–Object; no Schema attained (highest error stage: Object, n=5, 18.52%; no correct responses)	Schema attained (n=1, 3.70% correct); errors otherwise reached Object (n=4, 14.81%)	Schema attainment emerged mainly in the visual representation and, to a much more limited extent, in the verbal representation, whereas symbolic performance remained below Schema, indicating emerging representational asymmetry and unstable coordination.
High	Schema attained (n=1, 11.11% correct); errors otherwise reached Object (n=1, 11.11%)	Object only; no Schema attained (all errors at Object, n=9, 100%; no correct responses)	Schema attained (n=5, 55.56% correct); 2 errors also occurred at Schema (22.22%)	Symbolic representation remained the critical bottleneck. Schema-level integration was achieved in visual and verbal representations but not in symbolic representation, providing the clearest evidence of asymmetrical representational development.

In the low-ability group, students' errors ranged from comprehension to process-skill errors, although comprehension and transformation errors were the most prominent. As summarized in Table 9, cognitive construction remained predominantly at the Action stage across the three representations, with only limited progression to the Process stage in the visual task. Students tended to rely on mechanical procedures without developing a sufficiently integrated understanding of the conceptual structure of quadratic functions. At this level, therefore, representational development remained relatively similar across visual, symbolic, and verbal tasks, with no evidence of Schema attainment.

A more differentiated pattern emerged in the moderate-ability group. Students' errors became more varied, ranging from comprehension to encoding errors, while erroneous responses spanned the Action to Object stages. At the same time, correct and complete responses evidenced Schema-level attainment in the visual representation and, to a much more limited extent, in the verbal representation, whereas no Schema attainment was observed in the symbolic task (Table 9). This pattern provides evidence of an emerging cross-representational asymmetry, as cognitive development did not progress uniformly across the three representation types. Although students had begun to internalize procedures and recognize relationships among solution steps, their coordination across representations remained unstable, with symbolic representation showing comparatively weaker development.

This cross-representational asymmetry became most pronounced in the high-ability group. No comprehension errors were identified, and Schema-level attainment was evident in both visual and verbal representations (Table 9). In contrast, no Schema attainment was observed in the symbolic representation, where all erroneous responses were mapped to the Object stage. This contrast identifies symbolic representation as the primary bottleneck in students' representational development and provides the clearest evidence of asymmetrical representational development. The presence of Schema-level attainment in visual and verbal representations did not correspond to equivalent attainment in symbolic representation, indicating that cognitive development was representation-specific rather than uniform across representational forms. Moreover, two erroneous responses in the verbal representation were mapped to the Schema stage ($n=2$, 22.22%; Table 8), indicating that Schema-level reasoning did not necessarily eliminate difficulties in expressing or contextualizing the final mathematical result.

The interview analysis shows differences in the characteristics of difficulties across students' ability levels. Examples of interview results are shown in Table 10 below.

Table 10. *Summary of examples of interview results*

Ability	Visual	Symbolic	Verbal
Low	In this problem, there are no coordinate points. So I followed the words in the question. When it says move upward, I draw a line upward. And when it says horizontal distance, I draw a horizontal line.	I don't really understand how to form a quadratic function formula from a graph, so I guess what the function might be.	I still don't really understand word problems, so it's difficult for me to answer them.
Moderate	I answer the problem by plotting the coordinate points given in the question and then connecting them with straight lines.	Actually, I struggle with problems that have graph images, so to answer the question, I immediately use the formula I remember.	I know that I should use the formulas to determine the maximum values of x and y , but I am not sure whether the problem asks for the values of the variables separately or as an ordered pair, so I did not continue the solution.
High	I tried to draw the coordinate points given in the problem, but I couldn't figure out how to continue the graph. I know the graph should be symmetrical.	I can obtain the function formula, but I don't really understand the pattern of the quadratic function values. It seems irregular.	I know that the maximum value is 225000, but if I have to explain its meaning in the economic problem, I'm not very sure because I'm not used to it.

Based on the interview results, low-ability students experienced difficulties at the initial stage of problem-solving. They showed confusion in understanding the information in the problem and in determining the initial steps, which led to not completing the problem or to guessing the answer. Moderate-ability students showed progress in following the instructions in the problem and recognizing relevant formulas. However, students in the moderate group still experienced confusion in selecting the appropriate formula or in continuing the problem-solving procedure to obtain the answer. Meanwhile, high-ability students

did not experience difficulties in understanding the problem or using basic mathematical procedures. However, they showed confusion in interpreting calculation results in real-world contexts, particularly in distinguishing between mathematical and contextual meanings.

Discussions

The results of the study show that the average score for students' representations was 26.89%, indicating that students' mathematical representation ability remains generally low. However, the important finding of this study is not only the low average score, but also the presence of fairly clear differences between students' abilities in visual, symbolic, and verbal representations.

Based on Table 4, the symbolic indicator shows the lowest success rate across all ability groups, and there is no single correct answer. In contrast, in the visual and verbal indicators, although the success rate is still limited, the high-ability group shows relatively better performance. This pattern indicates that students' development of representation abilities is not evenly distributed across indicators.

The error analysis based on Newman's classification (Table 5) shows that in the symbolic indicator, errors are concentrated in the transformation and process skill categories at all ability levels. In the low-ability group, 83.33% of symbolic errors occur at the transformation stage. In the moderate group, errors are distributed between transformation and process skill. In the high-ability group, all symbolic errors occur at the process skill stage. This distribution indicates that the main obstacle in symbolic representation is not merely in understanding the initial information, but in the ability to transform visual representations into algebraic models, perform calculations and algebraic manipulation correctly, and determine the pattern of function values obtained.

Mapping symbolic errors onto the APOS stages (Table 7) further clarifies the cognitive structure underlying these difficulties. In the low-ability group, symbolic errors remained at the Action stage, indicating that students relied primarily on procedural actions without sufficiently internalizing the underlying relationships. In the moderate-ability group, erroneous responses extended from Action to Object, suggesting that some students had begun to internalize procedures and conceptualize quadratic functions more structurally, although this development remained inconsistent. In the high-ability group, all symbolic errors were mapped to the Object stage. Thus, although these students demonstrated a more advanced conceptual structure, they still experienced difficulties in carrying out symbolic processes accurately and consistently.

As synthesized in Table 9, this symbolic bottleneck becomes more apparent when APOS attainment is compared across the three representation types and ability groups. Schema-level attainment emerged in the visual and verbal representations among moderate- and high-ability students, whereas no Schema attainment was observed in the symbolic representation at any ability level. Instead, symbolic development remained within the Action-to-Object range, with Object representing the highest stage observed. This cross-representational contrast provides evidence of asymmetrical representational development, indicating that cognitive advancement in quadratic functions does not occur uniformly across representation types.

These findings demonstrate that the development of students' thinking in quadratic function material is representation-specific. This representation-specific development confirms that students may reach a higher stage in one form of representation, but this achievement is not necessarily stable in other forms of representation. In visual and verbal problems, moderate- and high-ability students are already able to understand the processes and concepts of quadratic functions quite well. However, students who have reached the Schema stage in visual and verbal representations still experience difficulties in symbolic representation. This pattern establishes that forming a stable Schema in quadratic function material requires mastery across multiple forms of representation rather than mastery of only one type. These results support the view that the ability to connect different forms of representation is very important in building deep mathematical understanding. Deep mathematical understanding cannot be constructed merely through mastery of a single form of representation, but through the ability to coordinate and connect various representations or models flexibly so that students can build a more comprehensive understanding and apply it in various contexts (Erath, Ingram, Moschkovich, and Prediger, 2021; Ke, Sadler, Zangori, and Friedrichsen, 2021; Kolar and Hodnik, 2021).

The interview results substantiate and extend this interpretation. In the symbolic indicator, a low-ability student stated, "I don't really understand how to make a quadratic function formula from a graph.

So I just guessed what the function might be.” This statement exemplifies the Action-stage characteristic, in which they are not yet able to perform the transformation from graphical representation to algebraic form in a structured manner.

A moderate-ability student expressed, “Actually, I don’t really like problems that involve graph images. So to answer the question, I use the formula that I remember.” This statement shows that the student has remembered and used formulas but has not yet been able to connect visual information with symbolic models meaningfully. This response indicates that the procedure has been internalized, but the coordination between representations has not yet been strongly formed.

Meanwhile, a high-ability student stated, “I can obtain the function formula, but I don’t know what the pattern of quadratic functions looks like.” This quotation underscores a critical gap, although a symbolic model can be constructed, understanding of the structure of quadratic functions as a complete concept is not yet fully stable. In the verbal indicator, a high-ability student stated, “I know the maximum value is 225000, but if I have to explain its meaning in an economic problem, I am not very sure.” The student’s response was classified as an encoding error under Newman’s framework because the final mathematical result was not expressed in the contextual form required by the problem. However, the interview evidence indicates that the underlying difficulty was not primarily notational; rather, it involved semantic translation or contextual mapping from a numerical result to its real-world meaning. Thus, successful symbolic calculation did not automatically lead to successful contextual interpretation.

Theoretically, these findings demonstrate that students’ transition from the Action, Process, Object, to Schema stages does not always occur smoothly. Such difficulties in the early stages can hinder the development of a comprehensive understanding (Umam and Susandi, 2022). In addition, students’ ability to understand and connect various forms of representation, such as graphs, symbols, and real contexts, strongly determines the strength of the conceptual understanding they construct (Altindis and Fonger, 2025; Li, Shen, Jiao, and Cai, 2022). These findings confirm that the type of representation used in a problem plays an important role in determining the stability of students’ cognitive development within the APOS framework. Although APOS theory explains that understanding develops gradually from action toward more comprehensive understanding, this study reveals that such development does not always occur equally across all types of representation. These results extend previous research, which has generally examined APOS stages and mathematical representation abilities separately.

In this study, symbolic representation proved to be the most difficult part for students. Symbolic representation requires students to understand concepts, transform information into algebraic form, and perform calculations correctly. This combination of demands causes many students to experience greater difficulty in symbolic representation compared to other representations. These difficulties extend beyond the calculation stage, encompassing also students’ ability to interpret and relate symbolic results to the problem’s context. These results corroborate previous studies showing that students tend to experience difficulties when solving problems involving symbolic representations, both in translating them into verbal or visual forms and when connecting symbols with the conceptual meanings they represent (Hariyani, Suherman, Andriani, and Herawati, 2023; Nurrahmawati, Sa’dijah, Sudirman, and Muksar, 2021).

The encoding errors observed among high-ability students in verbal problems reveal that successful calculation does not necessarily ensure successful contextual interpretation. Interview evidence suggests that these errors were associated with difficulties in semantic translation or contextual mapping rather than merely with the notation or production of the final answer. This finding underscores that even when students can complete symbolic calculations, they may still struggle to explain the meaning of the results in real-world situations. These results confirm that connecting calculation results with contextual meaning requires additional abilities. The ability required is the ability to coordinate various forms of representation comprehensively. This ability relates to efforts to maintain semantic congruence across representations, which involves not only procedural manipulation but also coordination of meaning between symbolic and verbal representation systems (Ayala-Altamirano, Pinto, Molina, and Cañadas, 2022; Castro, Cañadas, Molina, and Rodríguez-Domingo, 2022).

The main contribution of this study lies in emphasising that difficulties in symbolic representation are not merely procedural problems, but are related to coordination between representations in the formation of conceptual objects and schemas. This finding extends the application of APOS theory in the context of multiple representations by showing that achieving certain cognitive stages does not necessarily hold across all forms of representation. Students may demonstrate better understanding in one

representation, but still experience difficulties in other forms of representation.

These findings imply that learning quadratic functions should be designed to strengthen coordination among representations from the early stages. Learning approaches based on multiple representations and gradual scaffolding are believed to help students move more stably from the Action stage toward Schema. Several previous studies have found that learning interventions designed based on genetic decomposition within the APOS framework and combined with a multi-representation approach have been shown to facilitate coordination between representations and support the progression of students' mental construction from the Action stage toward Schema more systematically and stably (Baye, Ayele, and Wondimuneh, 2021; Borji, Martínez-Planell, and Trigueros, 2024; Siller, Nitzan-Tamar, and Kohen, 2023). This study extends previous findings by indicating that learning interventions need to consider that students at the Object stage still require support to integrate various forms of representation coherently until they reach the Schema stage.

This study is limited to one school context and uses a qualitative descriptive design, so the generalizability of the findings should be carefully considered. In addition, the analysis focuses on quadratic function material and does not directly test the effectiveness of learning interventions. Future research is recommended to develop experimental or quasi-experimental designs based on genetic decomposition within the APOS framework to test the effectiveness of multi-representation learning strategies empirically. Further studies may also examine the consistency of the cognitive development patterns identified in this study across different cultural and institutional contexts.

Conclusions

This study shows that difficulties in mathematical representation in the topic of quadratic functions are not only related to low procedural ability but are mainly associated with weak coordination among visual, symbolic, and verbal representations. Symbolic representation becomes the most challenging aspect for all ability groups. However, the main finding of this study is not merely the low scores achieved by students, but rather the different patterns of cognitive development across the forms of representation.

The integration of Newman's error classification with APOS theory reveals that certain types of errors are associated with students' stages of cognitive development. Low-ability students tended to remain predominantly at the Action stage, with comprehension and transformation errors being most prominent. Moderate-ability students exhibited an emerging uneven pattern of cognitive attainment across representations, with Schema attainment evident in the visual representation and, to a much more limited extent, in the verbal representation, whereas no Schema attainment was observed in the symbolic representation. This uneven pattern became most pronounced among high-ability students, who demonstrated Schema-level attainment in visual and verbal representations while symbolic performance remained at the Object stage.

These findings confirm that cognitive development in understanding quadratic functions is representation-specific rather than uniform across representational forms. We conceptualize this uneven pattern of APOS attainment as asymmetrical representational development, in which advancement to a higher cognitive stage in one representation does not necessarily correspond to equivalent attainment in another. Thus, this study extends the application of APOS theory in a multi-representation context by demonstrating that the formation of conceptual schemas is closely associated with students' ability to coordinate across representation systems.

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Conflict of interests

The authors declare that there is no conflict of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon request. Restrictions apply due to ethical and privacy considerations.

Institutional Review Board Statement

This study was conducted in accordance with the ethical standards for research involving human participants and in line with the principles of the Declaration of Helsinki. The research protocol was reviewed and approved by the Ethics Committee of [Universitas Padjadjaran] (Approval Number: [1290/UN6.KEP/EC/2024], 27 December 2024).

Prior to participation, informed consent was obtained from all participants. Participants were informed about the purpose of the study, procedures, voluntary participation, and their right to withdraw at any time without consequences. Confidentiality and anonymity of participants were strictly maintained.

Author Contributions

Conceptualization, H.M.S. and T.; methodology, H.M.S., N., and D.; formal analysis, H.M.S.; investigation, H.M.S.; validation, T., N., and D.; supervision, T., N., and D.; writing—original draft preparation, H.M.S.; writing—review and editing, H.M.S., T., N., and D. All authors have read and agreed to the published version of the manuscript.

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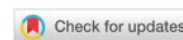
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The Effects of NTC Methods on Vocabulary Acquisition in Preschool Children

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Abstract: Introduction/Objective: Lexical development in early childhood is important for later literacy and academic success. This experimental study investigated the effectiveness of the NTC (Nikola Tesla Center) learning system, a pedagogical approach integrating movement, associative thinking, and play, on mother tongue vocabulary acquisition in preschool-age children. Methodology: A pre-test/post-test control group design was employed with 40 children (aged 22–34 months; 20 boys and 20 girls), equally divided into experimental and control groups. Participants completed a 20-item picture vocabulary test at three time points: initial, middle, and final. During four weeks, the experimental group participated in 12 NTC-based workshops involving motor-cognitive polygons, riddles, and associations, while the control group received standard curricular activities covering the same concepts. Due to non-normal data distribution, non-parametric statistics were used. Results: Groups did not differ significantly at initial testing ($p > .05$). Significant improvement over time was found for 19 of 20 target words in the experimental group ($p < .05$). The experimental group also demonstrated significantly greater vocabulary gains than the control group ($p < .05$), particularly for initially less familiar concepts, including iron, garlic, hyacinth, and nail. Progress was independent of age and gender, while dialectal forms were frequently replaced with standard forms by final testing. Conclusion: The findings suggest that integrating movement, associative thinking, and cognitive challenges may support vocabulary acquisition in early childhood. The greatest progress on less familiar words indicates potential benefits for deeper semantic learning. NTC-based activities may therefore represent a useful pedagogical approach for supporting lexical development and standard language competence in preschool children.

Keywords: early childhood, vocabulary development, lexical-semantic development, educational intervention.

Introduction

Mother tongue acquisition represents one of the most important developmental processes in early childhood and is connected with the overall cognitive, emotional, and social development of the child. Language development includes not only the acquisition of new words but also the development of meaning comprehension, symbolic thinking, connecting concepts, attention, memory, and communication ability. In the period of early and preschool age, the child's brain shows a high degree of neuroplasticity, which is why experiences from the environment have a significant impact on the formation of neural networks responsible for speech, thinking, and learning (Kolb and Gibb, 2011).

Contemporary research in neuroscience indicates that language development is not an isolated process but the result of a complex interaction of the brain's sensorimotor, emotional, and cognitive functions. Theories of "embodied cognition" emphasize that a child acquires the meanings of words and concepts through movement, experience, and interaction with the environment, not exclusively through verbal means (Barsalou, 2008; Glenberg and Gallese, 2012). Therefore, activities that include movement, object manipulation, visual representations, and thought processes can significantly contribute to

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language comprehension and vocabulary development.

Numerous studies (Pavličević-Franić, 2005; Jelaska, 2007; Aladrović Slovaček, 2019) confirm the connection between motor development and the development of higher cognitive functions. Diamond (2000) points out that motor activities are connected with the development of executive functions, attention, and learning abilities, while Piaget (1977) emphasizes that the development of thinking and language in children is based on active interaction with the environment. Vygotsky (1978) further indicates the importance of social interaction and play in the development of speech and thinking, believing that a child develops higher mental functions through joint activities and problem-solving situations.

In contemporary education, problems related to reduced attention, weaker vocabulary development, and difficulties in functional comprehension of read text among school-age children are increasingly pointed out. Therefore, the need for innovative learning approaches that actively involve the child and encourage thought processes instead of passive memorization of facts is growing.

The NTC Child Development Support System (abbreviated as NTC system) represents a pedagogical approach. The NTC system is based on activities designed to stimulate cognitive processes involved in learning, through activities that integrate movement, associative thinking, symbolic connection, problem-solving situations, and learning through play (Rajović, 2013). Activities such as hidden words, associations, illogical stories, puzzles, and motor-cognitive tasks have special importance in NTC as they encourage the activation of cognitive processes involved in learning.

In the area of mother tongue acquisition, NTC methods can have special significance because the child does not acquire new words through mechanical repetition but through connecting concepts, emotions, movements, and experiences. Such an approach can contribute to better understanding of word meanings, more efficient memorization, and greater functional use of language in everyday situations. The child's active participation in learning further increases motivation, attention, and interest in language activities.

Starting from these theoretical foundations, the main aim of this research is to examine the effects of NTC methods on vocabulary acquisition and lexical development in preschool children.

Lexical and Semantic Development

Parallel to grammatical development, lexical development also occurs, i.e., the process of word acquisition and the gradual construction of the child's mental lexicon. This is the most dynamic process of language development, which does not end when the child starts school but continues to develop almost throughout life (Hržica et al., 2015). Lexical development begins with the first word to which the child gives meaning and continues, with the child understanding many more words during the first year of life than they can independently pronounce. By the age of two, the child's vocabulary expands to approximately 50 to 200 expressions. During the second and third years of life, many children experience a rapid increase in vocabulary known as lexical spurt, when the child almost daily includes new words in their active vocabulary, often after just one encounter with them (Fenson et al., 1994). Vocabulary acquisition can be observed through receptive vocabulary, i.e., words the child understands, expressive vocabulary, i.e., words the child actively uses, thematic and lexical categories, i.e., types of words, and strategies for learning new words, which refers to inferring meaning from context, imitation, explicit teaching, and the like.

A significant stimulus for vocabulary development is provided by everyday situations in which the child actively participates – such as feeding, dressing, playing, and symbolic activities – as well as purposefully designed language situations in the family and preschool environment. Precisely through such interactions, the child connects words with concrete experiences, which contributes to deeper understanding and more permanent acquisition of concepts. Research shows that parents and educators who use a diverse and rich vocabulary, clearly name objects, describe actions and emotional states, and encourage the child to express themselves verbally significantly accelerate the lexical development process (Hoff, 2006). During this process, various language errors are common and are considered an integral part of natural language acquisition. Such errors, including overly broad or overly narrow use of words, indicate the child's attempt to actively apply new knowledge, which is a sign of cognitive processing and formation of lexical categories. Thus, in lexical development, neologisms appear, i.e., new words the child uses to cover their so-called "lexical gaps," i.e., ignorance of certain words, so they invent them, with examples from Croatian/Serbian child language that include strujakač for utikač (plug), pišalica for olovka (pencil), tepihač for otirač (doormat), and the like (Pavličević-Franić, 2005). From all these examples, it can be

seen that the child understands word formation but lacks semantic knowledge, which they gradually acquire. Also, the child hypergeneralizes in this process, calling all four-legged animals, for example, “dog,” or hypospecifics by using limited word use in a familiar context. All these errors show that the child is actively building and testing their linguistic system and should be viewed as an integral part of the process of natural language acquisition, not as developmental difficulties. Lexical development in preschool age has long-term implications because it is strongly correlated with later literacy development, comprehension of read content, and school achievement. Children who acquire a richer vocabulary in early childhood are associated with more advanced cognitive strategies, more pronounced verbal abilities, and a higher degree of social competence (Tabors et al., 2001). Furthermore, vocabulary development is directly connected with the reading process, and reading comprehension will greatly depend on vocabulary development and knowledge of semantic categories. The results of standardized tests (PISA, 2018 and PIRLS, 2021) show that reading competencies and skills are directly connected with vocabulary development because reading diverse texts and exposure to different words in various functional styles yields better results, as does motivation, which is built as early as the early language period. Although this research focuses on the vocabulary of early and preschool children, these results of international research on reading competence confirm that poorer reading habits, which are developed precisely at this age, consequently have a poorer vocabulary and, consequently, poorer reading competence. Namely, if a child does not understand 90-95% of the words in a text, he or she has difficulty in reading comprehension, which is an increasingly common problem for children of primary school age. Therefore, the development of vocabulary at an early age is important as a predictor of, among other things, reading competence.

Finally, the importance of lexical development in preschool age is reflected not only in the number of acquired words but also in the way the child uses language to express thoughts, emotions, and needs. Through everyday situations and interactions, the child gradually builds their own vocabulary and develops increasingly complex language patterns. The role of adults in this process is extremely important because they, through their example, patience, and encouragement, shape the language environment that can accelerate or slow down this development. Precisely for this reason, it is necessary to be aware of how valuable every word, question, or comment addressed to the child is as an opportunity for learning and progress, i.e., the richer and more sensitive the environment is to the child's communication needs, the more long-term and significant the results in vocabulary development will be.

NTC Child Development Support System

The NTC (Nikola Tesla Center) learning system represents a neuro-pedagogical approach that integrates cognitive, motor, and language development through play, movement, and thought activation (Rajović, 2018). The underlying mechanism of this approach can be conceptualized as follows: NTC activities → active child engagement → connection between concepts and experiential learning → enhanced word retention → richer vocabulary development. Through carefully designed tasks, children acquire language structures spontaneously during play and interaction, simultaneously expanding vocabulary and developing syntactic and semantic competence (Rajović, 2013).

The core mechanisms of the NTC method include: creating associations (connecting words with movements, objects, or situations); developing thought categories (classification and differentiation of concepts); learning through puzzles and logical problems (verbal problem-solving); word play (rhyme, rhythm, and homonyms for phonological awareness); and movement as language support (verbal expression accompanying physical activity) (Rajović, 2013). In practice, children are encouraged to express themselves through complete sentences during play—describing situations, conveying information, or reacting to verbal instructions—within emotionally engaging contexts that enhance attention and motivation (Rajović, 2018).

The NTC system is grounded in several key principles: early stimulation of developmental potential through activities targeting critical periods of neuroplasticity; active learning through play and movement that connects motor and cognitive development; associative and divergent thinking that encourages concept connection and meaning creation; emotional engagement through humor and interactive tasks; and coordination between family and institutional environments to ensure optimal development (Rajović, 2018). Special emphasis is placed on developing functional knowledge—the child's ability to apply acquired language skills in real situations rather than merely reproducing them mechanically.

Practical applications include activities such as visual-verbal integration (recognizing and naming

moving objects), word play (rhymes, opposites, syllable combinations), and motor-cognitive games. A typical example involves children performing physical tasks (e.g., jumping over marked fields) while simultaneously responding to verbal prompts—classifying words by grammatical category, naming objects, or creating sentences. Other activities encourage spatial-temporal orientation (“Stand below, go above”) or logical sequencing (“First take... then put... finally show...”). The “language path”—a physical polygon where children complete motor tasks while responding to verbal challenges—exemplifies tasks integrated into daily practice (Rajović, 2013). And it is of great importance to mention, although NTC methods have gained popularity in educational practice, empirical evidence regarding their effectiveness remains limited and requires systematic evaluation. And, to be more specific, empirical evidence regarding the effectiveness of NTC methods in early vocabulary acquisition remains limited.

Aim, Problems, and Hypotheses of the Research

The main aim of this research is to examine the effects of NTC methods on vocabulary acquisition and lexical development in preschool children

The following research tasks arise from the main aim:

1. To assess children’s ability to name target concepts based on visual stimuli.
2. To examine whether the use of NTC methods has a statistically significant effect on the lexical development of early-age children in terms of the number of correctly named terms before and after of using NTC methods in preschool teaching
3. To determine whether there is a statistically significant difference in results with respect to the group to which participants belong: control and experimental.

In accordance with the main aim and research tasks, the following hypotheses are set:

H_1 : It is expected that the experimental group will be more successful in acquiring lexical concepts than the control group precisely due to exposure to NTC teaching methods.

H_2 : Children will achieve higher initial scores for familiar everyday concepts compared with less frequently encountered concepts.

H_3 : Children exposed to NTC activities will show improvement in naming target concepts after the intervention.

Methodology

Description of the Sample and Research Implementation Method

The research was conducted in two toddler educational groups with a total of 40 children in one kindergarten in Slavonia, Croatia with children from the age of 2 to 3 years old. One group was the control group and the other the experimental group, with 20 children tested in each group. The sample included a total of 20 boys and 20 girls, evenly distributed in both groups. Before the start of the research, consent forms were distributed to parents for participation in the research, and only those children whose parents signed the consent form participated in the research, in accordance with the Code of Ethics for Research with Children.

In the experimental group, activities were conducted three times a week within a time frame of 4 weeks, from March 17, 2025, to April 17, 2025. Participants were tested before the start of the research, after two weeks, and after the completion of the research, and all their answers were recorded in a research table created for the purposes of this research. Participants in both the control and experimental groups were tested at the same time intervals, and only participants in the experimental group were exposed to NTC activities during the month of experiment implementation. The design of the conducted research was quasi-experimental pretest-posttest control group design

Due to a small sample ($N = 40$), the Shapiro-Wilk test was used to determine the distribution of the data.

Research Instrument

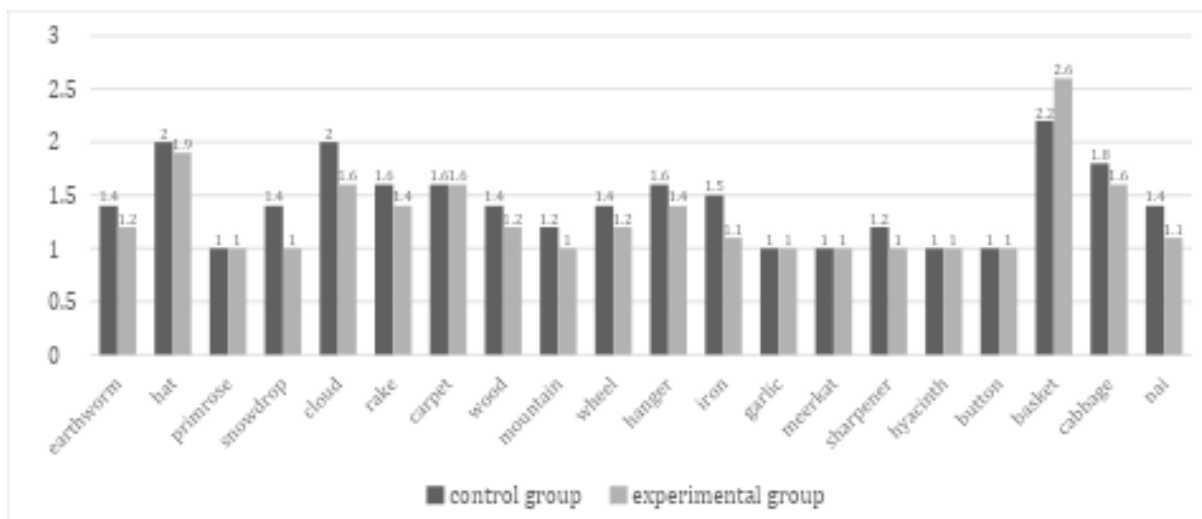
For the purposes of this research, a test was created in which students were required to name a concept after the researcher showed them a picture containing that concept. The terms were selected from picture books that are read to children of this age in accordance with the Early Childhood and Preschool Education Curriculum. A pilot study was conducted to check the appropriateness of the se-

lected items. Based on the results of the pilot study, an analysis of the items was conducted, including an assessment of their discriminativeness, and the internal consistency of the test was assessed using Cronbach's alpha coefficient ($\alpha = 0.84$). In accordance with the results of the analyses, some items were excluded, and the final version of the test was used in the main study. All forms of the stated concept with possible mispronunciations or naming of the concept in dialect were taken as correct answers. The concepts were chosen from the children's immediate reality, from picture books that were read during that period, and were connected to categories of words that participants were more intensively producing and encountering during that period. The selected concepts that were tested and later processed through NTC methods were the following: *glista*, *šešir*, *jaglac*, *visibaba*, *oblak*, *grablje*, *tepih*, *šuma*, *planina*, *kotač*, *vješalica*, *glačalo*, *češnjak*, *merkat*, *šiljilo*, *zumbul*, *gumb*, *košara*, *kupus*, *čavao*. These concepts translate to: earthworm, hat, primrose, snowdrop, cloud, rake, carpet, woods, mountain, wheel, hanger, iron, garlic, meerkat, sharpener, hyacinth, button, basket, cabbage, nail. A total of 20 concepts were tested, several of which contain palatal consonants and are therefore more difficult to pronounce (e.g., *čavao*, *češnjak*, *šiljilo*). Also, these are representable concepts that are easy to depict visually. The words were selected from stories that are read to children of that age according to the Curriculum for Early and Preschool Education. Given that the words need to represent both terms that appear more frequently and those that appear less frequently in order for the test to be valid, the term "merk" was chosen as a term that is not common in children's vocabulary of that age, but that is precisely why it is a good example of a term that can be acquired using different working methods or through reading, given that it appears in a story, and children of that age are happy to name terms from the animal category.

To conduct the research in the experimental group, participants were exposed to NTC methods for one month, three times a week. These activities were most often implemented in the form of a polygon with stations that participants had to follow and, during the performance, perform other language tasks, such as naming a concept from a card, listing concepts, categorizing concepts, naming concepts, and the like. The polygons contained elements of crawling, walking, climbing, descending, jumping, threading, throwing, and the performance required coordination, balance, precision, and flexibility. Three different types of polygon setups were used. Also, before the polygon, there was always a warm-up and familiarization with the concepts that participants had to place in different contexts (The earthworm comes out in the rain., There is a wolf in the forest., The button is on the shirt.). All activities were implemented by educators. In the experimental group, educators prepared activities using the NTC method, and in the control group, educators prepared activities in the classic, or standard, way that is usually done with children of that age. Each activity lasted about 20 minutes, which is how long activities in kindergarten usually last, in accordance with the children's attention span and other tasks that are carried out during a pedagogical day. In the control group, the teacher simultaneously encouraged the children to acquire the same target words in the classic way, as is usually done in preschool institutions, following the given plan and program, but without using the NTC teaching method. The control group spent around the same time partaking in activities for learning the words with the teacher. During the experiment implementation, participants were tested three times: at the beginning, in the middle, and at the end, and the results were compared in this way.

Results

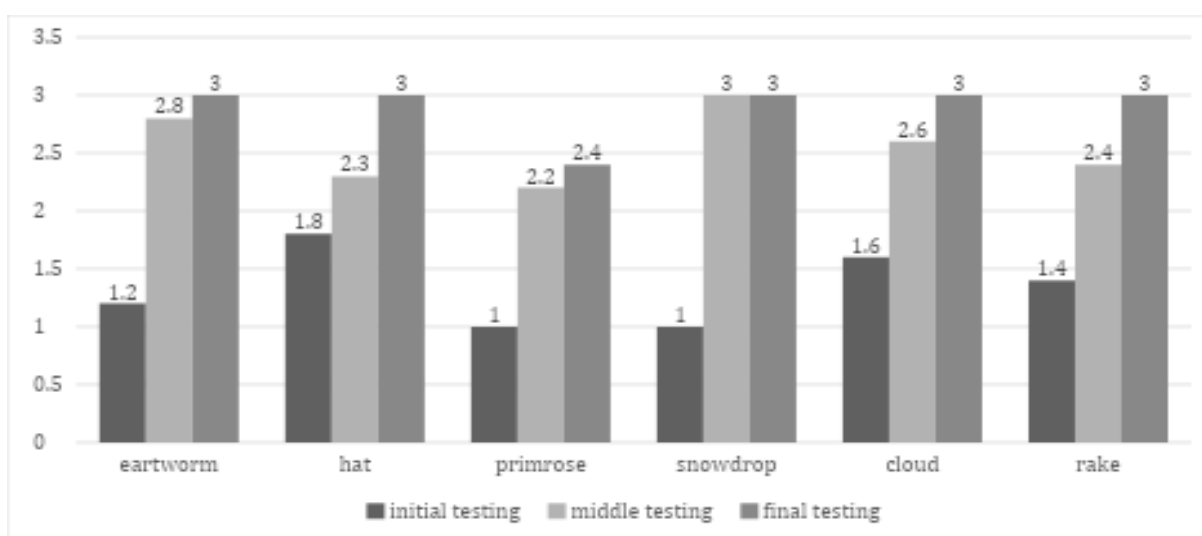
The first research task was to determine the knowledge of target words at the recognition level. Namely, the initial word knowledge test was done in both groups to see if they differed in initial knowledge [Graph 1]. The Shapiro-Wilk test showed that there was no statistically significant difference in knowledge of each target word ($p > 0.05$, $df = 39$).



Graph 1. Display of arithmetic means – knowledge of target words (initial testing)

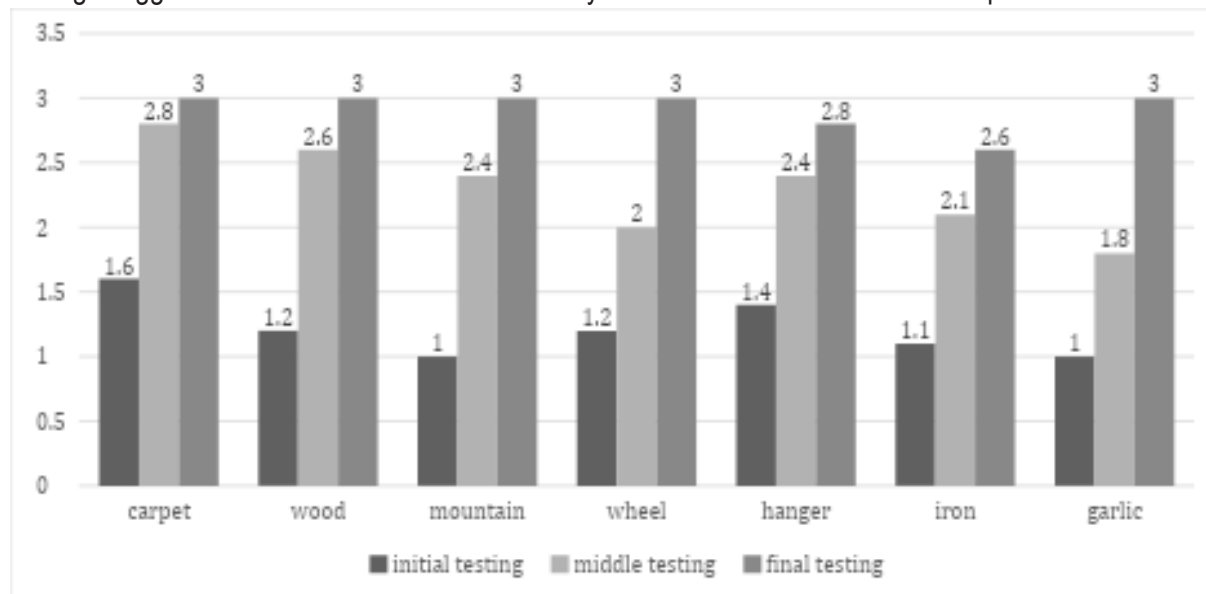
Initial results showed that participants were most successful in knowing the target words: basket, hat, cloud, and cabbage. The findings may indicate that familiarity with everyday experiences contributes to better initial word knowledge. Basket is a word often associated with the fairy tale Little Red Riding Hood, cabbage is often on their daily menu, hat they associate with a clown, and clouds are often mentioned in the context of weather conversations, and children of that age often draw them. The concepts primrose, garlic, market, sharpener, hyacinth, button were words whose meaning most participants could not determine, probably because they were not used in their speech environment. These results confirm the first set hypothesis, which expected that children in the initial testing would be more familiar with concepts from their everyday environment than with other concepts, such as, e.g., market.

The second research problem was to examine whether the use of NTC methods has a statistically significant effect on the lexical development of early-age children. The results of the initial, middle (after 2 weeks of experiment implementation), and final testing are presented. The first display [Graph 2] shows the results of the first six tested words: earthworm, hat, primrose, snowdrop, cloud, rake. For all six words, the Kruskal-Wallis test ($p < 0.05$, $df = 39$) shows that there is a statistically significant difference between the initial, middle, and final testing. Namely, during the experimental implementation of the program that included NTC methods, children demonstrated improved retrieval of target words.



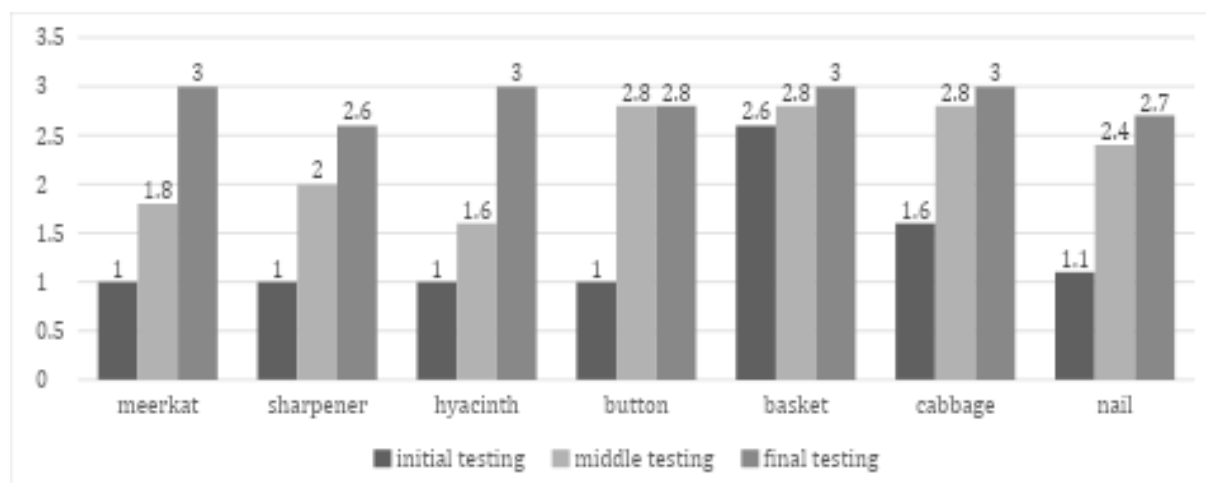
Graph 2. Display of initial, middle, and final results of word recognition testing: earthworm, hat, primrose, snowdrop, cloud, and rake

The second display [Graph 3] shows the results of the other seven tested words: carpet, forest, mountain, wheel, hanger, iron, and garlic. For all seven words, the Kruskal-Wallis test ($p < 0.05$, $df = 39$) shows that there is a statistically significant difference between the initial, middle, and final testing. These findings suggest that the use of NTC methods may be associated with lexical development.



Graph 3. Display of initial, middle, and final results of word recognition testing: carpet, forest, mountain, wheel, iron, hanger, garlic

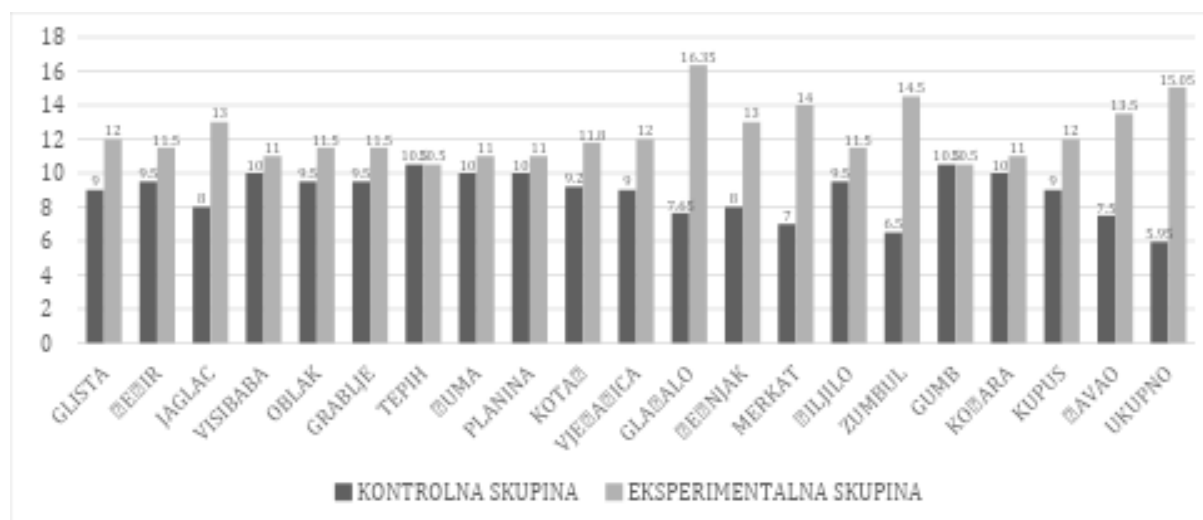
The third display [Graph 4] shows the results of the last seven of the twenty tested words: market, sharpener, hyacinth, button, basket, cabbage, and nail. For six of the seven words, the Kruskal-Wallis test ($p < 0.05$, $df = 39$) shows that there is a statistically significant difference between the initial, middle, and final testing. There is no statistically significant difference only for the word “basket” ($p > 0.05$, $df = 39$). For these seven words, the findings suggest a positive association between the use of NTC methods and lexical diversity, indicating their potential to support the development of lexical competence.



Graph 4. Display of initial, middle, and final results of word recognition testing: market, sharpener, hyacinth, button, basket, cabbage, nail

The analysis of the conducted tests on target words shows that all concepts have a tendency to grow during the research. The arithmetic mean values in the initial testing vary between 1.0 and 2.6, while in the final testing almost all reach 3.0. Concepts such as hanger, iron, and garlic do not reach the maximum value of 3, but still record significant progress. In accordance with the obtained results, the second set of hypotheses was partially supported. The findings suggest that children demonstrated progress in lexical development after participating in activities based on NTC teaching methods.

The third research problem was to determine whether there is a statistically significant difference in results with respect to the group to which participants belong: control and experimental. The results of the Mann-U-Whitney test show that there is a statistically significant difference in the overall results of the control and experimental groups ($p < 0.05$, $df = 39$) [Graph 5]. If we look at individual words, a statistically significant difference between the control and experimental groups exists for the words iron, garlic, market, hyacinth, nail ($p < 0.05$, $df = 39$) and in the overall result ($p < 0.05$, $df = 39$). The results show that children in the experimental group successfully acquired all concepts, especially those that were less familiar to them in the initial testing. The obtained results are consistent with the hypothesis that the experimental group demonstrated greater success in acquiring lexical concepts than the control group after participating in activities based on NTC teaching methods.



Graph 5. Display of results for each target concept – results of the control and experimental groups

During all three testing points, it was observed that children name concepts in their organic idiom, which is completely expected and in accordance with developmental age. During the early period, children are “immersed” in the language and speech of their environment, which significantly affects the development of lexical competence. For example, instead of glačalo (the standard word for iron), a very common answer was pegla, a foreign word very often used in dialect in spoken language. Also, participants often used the dialectal expression točak instead of kotač (wheel). When naming the concept čavao (nail), they also often used the dialectal form ekser. Dialectal words appeared significantly more often in the initial testing, while by the end of the research children gradually acquired additional standard-language labels alongside familiar dialect forms, given that during the encouragement of children’s lexical development using NTC methods and approach, standard forms of these words were used. Half of the participants who used regional lexical forms in the initial testing used standard forms of these words in the final testing. This research also partially supported that dialect, especially in early age, affects the learning of concepts from the immediate environment, i.e., that children name some concepts in their organic idiom.

Discussion

Based on the presented results, it can be concluded that the research provided preliminary evidence of the potential contribution of NTC methods on the lexical development of early-age children. The findings confirm all four set hypotheses and indicate the importance of systematically encouraging vocabulary development through activities that include play, connecting concepts, and active cognitive engagement of the child.

Initial Level of Knowledge of Target Words

The results of the initial testing showed that there were no statistically significant differences between the control and experimental groups in knowledge of target words, indicating comparable initial levels of performance between groups. and enabling reliable monitoring of the effects of the experimental

program. Children best recognize concepts belonging to their everyday experience and immediate environment, such as basket, hat, cloud, and cabbage. In contrast, they were less familiar with less common concepts such as primrose, hyacinth, market, or sharpener. This pattern confirms that early lexical development predominantly relies on the frequency of contact with certain concepts and their use in the family and peer environment. The findings are in accordance with theoretical assumptions about situational and experiential language learning, according to which words are first acquired through everyday communication, which is consistent with the findings of other research (Filipe et al., 2023).

Effectiveness of NTC Methods in Lexicon Development

The results obtained during the middle and final measurements showed statistically significant improvement in knowledge of almost all target words. For most concepts, a continuous increase in scores from the initial to the final testing was observed, with arithmetic means reaching or approaching the maximum value. This pattern suggests that children demonstrated an improved ability to retrieve and use newly introduced lexical items, which is consistent with the findings reported by Spataro et al. (2024) and Scionti et al. (2023).

Particularly noteworthy is the finding that the greatest improvement was observed for the words that were least familiar to children at the beginning of the study. This pattern suggests that NTC methods may have supported not only the consolidation of existing knowledge but also the acquisition of new and less familiar concepts. It is possible that activities based on connecting information, associative learning, movement, and problem-solving contributed to children's ability to acquire and recognize new lexical units. This interpretation is consistent with the findings of Filipe et al. (2023), Spataro et al. (2024), and Scionti et al. (2023), who reported associations between working memory, cognitive flexibility, executive functions, and language and vocabulary development.

The only exception was the word *basket*, for which no statistically significant difference between measurements was observed. One possible explanation is that this concept was already familiar to most participants at the beginning of the study, leaving limited opportunity for further improvement. This pattern may reflect a ceiling effect, whereby high initial performance reduces the likelihood of detecting statistically significant gains, a phenomenon also reported by Flores et al. (2020).

Differences Between the Experimental and Control Groups

Comparison of the control and experimental groups showed a statistically significant advantage of the experimental group in overall achievement, as well as with several individual concepts that were less familiar to children at the beginning of the research (iron, garlic, market, hyacinth, and nail). These findings suggest that the observed improvement may be associated with NTC activities. This finding can be connected with Flores et al. (2020), which shows that children acquire new meanings by connecting new words with already existing lexical networks.

It is especially important that differences between groups are most clearly observed precisely with more complex and less familiar concepts. This shows that the NTC approach has its greatest effect in situations where it is necessary to expand children's vocabulary beyond everyday experience. Such results partially support the notion that the NTC program represents an effective model for encouraging lexical diversity and enriching the vocabulary of preschool-age children. This finding is supported by Anderson et al. (2025), who emphasize that a rich language environment contributes to vocabulary development and school readiness.

Influence of Dialect on Lexical Development

The research results also indicate a significant role of dialect in early language development. During the initial testing, children often used local or regional lexical forms, such as *pegla* instead of *glačalo* (iron), *točak* instead of *kotač* (wheel), and *ekser* instead of *čavao* (nail). This phenomenon is expected at an early age because lexical development occurs primarily within the language environment in which the child grows up.

However, it is interesting that during the research, there was a gradual increase in the use of standard language forms. Since standard words were consistently used during NTC activities, a significant number of children gradually acquired additional standard-language labels alongside familiar dialect forms. This finding may be related to the phenomenon that NTC methods, in addition to contributing to

vocabulary enrichment, could possibly also have an important role in the development of standard language competence, without suppressing the child's natural dialectal identity. This is in accordance with the findings of Muir et al. (2023) and Kellens et al. (2023), which indicate that programs based on active participation, interaction, and self-regulation have positive effects on the cognitive and language development of preschool children.

Overall, the research results confirm that the lexical development of early-age children is strongly connected with experience, frequency of exposure to concepts, and the quality of pedagogical stimuli. The application of NTC methods proved to be an effective approach for expanding vocabulary, acquiring new concepts, and improving lexical competence. It is especially significant that the greatest effects were achieved with less familiar words, indicating the potential of the NTC approach to encourage the development of higher levels of language functioning. At the same time, the results confirm the importance of the dialectal environment in early language acquisition, but also the possibility that through planned educational activities, standard language expression can be successfully developed. These findings indicate that NTC methods deserve further empirical evaluation, as a means of encouraging the child's linguistic, cognitive, and overall development. The previous findings are in accordance with the findings of Torppa et al. (2021) and the review by Dilla and Jayadinata (2025), which emphasize the importance of a stimulating family and educational environment for early language acquisition.

Conclusion

The present study provides preliminary evidence that the NTC learning system may support lexical development in early childhood. The experimental group demonstrated significantly greater vocabulary gains than the control group, particularly for less familiar concepts. These findings suggest that pedagogical activities integrating movement, associative thinking, and play may facilitate the acquisition and integration of new lexical units.

The findings are consistent with theoretical frameworks emphasizing the interconnection between motor, cognitive, and linguistic development (Diamond, 2000; Glenberg and Gallese, 2012). By engaging children in activities requiring simultaneous physical coordination and verbal production, the NTC method may support cognitive processes involved in vocabulary learning while fostering intrinsic motivation and curiosity, both of which have been identified as important factors in children's later literacy development.

Nevertheless, the findings should be interpreted with caution due to the limited sample size, relatively short intervention period, and focus on typically developing children within a single preschool setting. Consequently, the results cannot be readily generalized to children with diagnosed language difficulties, different educational contexts, or older age groups. Future research should employ longitudinal designs, larger and more diverse samples, and additional outcome measures to examine the durability of vocabulary gains and the extent to which they transfer to broader language and literacy skills, such as reading comprehension and expressive writing.

Despite these limitations, the findings suggest that the NTC method may represent a valuable addition to preschool educational practice. If supported by further research, its systematic integration into preschool curricula could contribute to vocabulary enrichment and the development of foundational communication competencies that underpin later learning.

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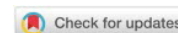
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Developing Students' Cultural Competence Through Cultural Geography Education: The Role of Project-Based Learning and Digital Technologies

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Abstract: Increasing cultural diversity and globalization require higher education institutions to prepare future geography teachers who can work effectively in culturally diverse environments. Developing cultural competence has therefore become an important objective of geography teacher education, requiring instructional approaches that combine disciplinary knowledge with authentic learning experiences and digital innovation. This study investigated the effectiveness of integrating project-based learning (PBL) and digital technologies into a Cultural Geography course to enhance university students' cultural competence. A mixed-methods quasi-experimental design was employed involving 73 second-year geography students, including 35 students in the control group and 38 students in the experimental group. The intervention was implemented over one academic semester. Quantitative data were collected using the Cultural Competence Questionnaire and analysed through mixed repeated-measures ANOVA, while qualitative data from classroom observations, reflective journals, and project reports were analysed using thematic analysis. The results showed that students in the experimental group achieved significantly greater improvements than the control group across all dimensions of cultural competence, including cultural knowledge, cultural sensitivity, cultural skills, and cultural interaction. Qualitative findings further indicated that project-based learning, cultural mapping, and digital technologies, including NetLogo, AnyLogic, and Cesium, enhanced students' engagement, spatial thinking, collaborative inquiry, and understanding of cultural phenomena. Although the study was limited by its relatively small sample from a single university and the one-semester duration of the intervention, the findings provide empirical evidence that integrating project-based learning with digital technologies represents an effective pedagogical approach for strengthening cultural competence in geography teacher education and offers practical implications for competence-oriented curriculum development in higher education.

Keywords: cultural competence, cultural geography, project-based learning, digital technologies, geography teacher education, higher education.

Introduction

Rapid globalization, international mobility, and digital transformation have substantially increased cultural interaction across contemporary societies. As a result, higher education institutions are expected to prepare graduates who can engage effectively with culturally diverse communities while preserving cultural heritage and promoting intercultural understanding. Such challenges are particularly relevant in Kazakhstan, where cultural diversity and historical heritage play an important role in shaping national identity. [Turkey \(2022\)](#) argues that globalization simultaneously stimulates cultural innovation and transforms long-established cultural practices, creating a need to balance openness to global influences with the preservation of cultural heritage.

These developments have increased the importance of cultural competence in education. Educational institutions are expected not only to transmit knowledge but also to prepare learners to engage ef-

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fectively in culturally diverse environments. In this context, cultural competence is increasingly associated with the ability to understand cultural differences, communicate across cultural boundaries, and participate constructively in multicultural societies. Byram (1997) and Cross et al. (1989) emphasize that such competence extends beyond factual knowledge and encompasses values, attitudes, and behavioural dispositions that support meaningful intercultural interaction.

The complexity of cultural competence has led researchers to conceptualize it as a multidimensional construct. Effective participation in culturally diverse contexts requires not only knowledge of cultural traditions and social practices but also openness toward cultural differences and the ability to apply these qualities in authentic situations. Flaskerud (2007) associates these dimensions with cultural knowledge, cultural sensitivity, and community interaction, highlighting the interconnected nature of cultural competence development.

Within higher education, identifying effective approaches to developing cultural competence has become an important educational priority. Geography occupies a distinctive position in this process because it examines the relationships among people, culture, and space. Through the study of cultural landscapes, place identity, and spatial behaviour, geography encourages students to explore how cultural processes are expressed in different geographical contexts. Morgan (2001) notes that geography education provides opportunities to investigate cultural identities and human experiences of place alongside natural and economic processes.

Among the branches of geography, Cultural Geography offers particularly strong potential for addressing issues related to culture and identity. The field focuses on the spatial organisation of cultural phenomena and examines how meanings, values, and social practices become embedded in places and landscapes. Hall and Johnston-Anumonwo (2016) emphasize that cultural landscapes, ethnocultural regions, and processes of cultural diffusion provide important perspectives for understanding the relationship between culture and space.

The educational value of Cultural Geography extends beyond disciplinary knowledge. Learning activities involving cultural landscapes, regional cultural characteristics, and cultural mapping encourage students to explore cultural diversity from geographical perspectives. Such experiences strengthen spatial reasoning, analytical thinking, and awareness of cultural differences while creating meaningful opportunities for competence-oriented learning.

Despite growing scholarly interest in cultural competence, most existing studies have examined its development within language education, teacher education, healthcare, and intercultural communication. Comparatively less attention has been devoted to investigating how discipline-specific courses can systematically foster cultural competence through authentic learning experiences.

Within geography education, Cultural Geography offers considerable potential for developing students' understanding of cultural diversity through the study of place, landscape, and spatial relationships. However, empirical evidence regarding the integration of project-based learning and digital technologies into Cultural Geography for the purpose of developing cultural competence remains limited. Accordingly, there is a need to design and empirically evaluate instructional approaches that integrate Cultural Geography with project-based learning and digital technologies to strengthen students' cultural competence in higher education.

Accordingly, this study aimed to examine the effectiveness of a Cultural Geography course integrating project-based learning and digital technologies in developing students' cultural competence. To achieve this aim, the following objectives were established:

- To analyze the theoretical foundations and structural components of cultural competence;
- To identify the pedagogical potential of Cultural Geography for fostering cultural competence;
- To design and implement a Cultural Geography course integrating project-based learning and digital technologies;
- To evaluate the effectiveness of the proposed instructional approach through a pedagogical experiment.

Accordingly, the study addressed the following research question:

To what extent does a Cultural Geography course integrating project-based learning and digital technologies contribute to the development of students' cultural competence?

Literature Review

Theoretical Foundations of Cultural Competence

The increasing cultural diversity of contemporary societies has positioned cultural competence as a fundamental outcome of higher education. Universities are expected not only to develop students' disciplinary knowledge but also to prepare graduates who can communicate effectively, collaborate across cultures, and respond responsibly to global social and cultural challenges. Consequently, cultural competence has become closely associated with global citizenship, social inclusion, and education for sustainable development (Byram, 1997; Cross et al., 1989).

Cultural competence is widely recognised as a multidimensional construct incorporating cognitive, affective, and behavioural dimensions. Deardorff (2006) conceptualises cultural competence as the integration of cultural knowledge, attitudes, skills, and appropriate behaviour that enables individuals to interact effectively in culturally diverse contexts. Similarly, Flakerud (2007) emphasises that cultural competence extends beyond awareness of cultural differences to include empathy, respect, and the ability to adapt communication and behaviour across cultural settings.

Recent international educational frameworks further reinforce the importance of cultural competence within higher education. UNESCO (2021) highlights intercultural dialogue, cultural diversity, and global responsibility as essential educational priorities, while the OECD (2018) identifies global competence as a key outcome that enables learners to analyse global issues, appreciate multiple perspectives, and engage constructively with individuals from different cultural backgrounds. More recent research suggests that digital competence and intercultural competence are becoming increasingly interconnected as higher education integrates technology-rich learning environments. Digital learning environments support collaborative inquiry, intercultural communication, and authentic learning experiences that contribute to competence-oriented education (Vojteková et al., 2023; Lee, 2023).

Despite extensive research in teacher education, healthcare, and language education, comparatively little attention has been devoted to examining how Cultural Geography can systematically contribute to the development of cultural competence. This gap highlights the need for discipline-specific pedagogical models that integrate geographical inquiry with competence-oriented learning.

Pedagogical Potential of Cultural Geography

Culture and geographical space are inherently interconnected, making Cultural Geography a valuable disciplinary context for developing students' cultural competence. The discipline explores cultural landscapes, place identity, cultural diffusion, ethnocultural regions, and the spatial organisation of human activities, enabling students to understand how culture is shaped by geographical processes (Morgan, 2001; Winders, 2014; Hall and Johnston-Anumonwo, 2016).

From an educational perspective, Cultural Geography supports inquiry-based and student-centred learning by encouraging learners to investigate authentic geographical problems through fieldwork, cultural mapping, spatial analysis, and collaborative investigation. These learning experiences foster critical thinking, spatial reasoning, intercultural awareness, and reflective learning while connecting theoretical concepts with real-world cultural phenomena.

The educational potential of Cultural Geography is further strengthened through the integration of project-based learning and digital technologies. Contemporary geography education increasingly incorporates Geographic Information Systems (GIS), digital mapping platforms, geospatial simulations, virtual learning environments, and immersive technologies to support active learning and spatial inquiry. Recent studies demonstrate that web-based GIS, augmented reality, virtual reality, and mobile learning improve students' spatial thinking, inquiry skills, collaborative learning, and engagement in geography education (Vojteková et al., 2023; Lee, 2023). Empirical evidence from higher geography education further supports these findings. Grobelski et al. (2023) demonstrated that project-based geography courses enabled undergraduate students to develop stronger geographical inquiry skills, intercultural understanding, collaborative learning, and ethical awareness through authentic research projects. Similarly, Yan et al. (2023) reported that blended GIS-supported learning significantly improved students' learning experiences, motivation, and perceived learning outcomes in higher education by integrating active learning with digital geospatial technologies. Systematic reviews further indicate that successful implementation depends on

adequate teacher preparation, curriculum design, and technological infrastructure.

Consequently, integrating project-based learning with geospatial technologies provides opportunities for students to investigate authentic cultural issues, construct knowledge collaboratively, and develop competencies required for professional practice in increasingly digital and culturally diverse societies.

Empirical Research on Developing Cultural Competence

Empirical research consistently demonstrates that active learning approaches contribute more effectively to competence development than traditional lecture-based instruction. Project-based learning encourages students to investigate authentic problems, collaborate with peers, reflect on their experiences, and apply theoretical knowledge in practical contexts. Such learning environments have been associated with improvements in intercultural understanding, communication, critical thinking, and self-directed learning (Thomas, 2000; Bell, 2010; Deardorff, 2006).

The growing integration of digital technologies has further expanded opportunities for competence-oriented learning in geography education. Recent literature reviews indicate that GIS applications, geospatial technologies, digital mapping platforms, and virtual learning environments enhance students' spatial reasoning, motivation, collaborative inquiry, and digital competence while supporting more authentic and interactive learning experiences (Vojteková et al., 2023; Panjaitan et al., 2023). Nevertheless, these reviews also identify persistent challenges related to infrastructure, teacher preparedness, and effective pedagogical integration.

Recent empirical studies also provide evidence that project-based and technology-supported geography education positively influences students' engagement and disciplinary competencies. For example, Grobelski et al. (2023) found that project-based learning transformed students' understanding of geography from factual knowledge acquisition to active geographical inquiry through authentic collaborative projects. Likewise, Cascante-Campos (2023) demonstrated that university instructors who perceived greater pedagogical value in geospatial technologies were significantly more likely to adopt GIS-based teaching practices, highlighting the importance of digital pedagogy in higher geography education.

Although the educational benefits of project-based learning and digital technologies have been widely acknowledged, empirical evidence concerning their combined application within Cultural Geography remains limited. Most previous studies have focused on geography education broadly, digital competence, or technology integration, whereas comparatively few have investigated how project-based learning and digital technologies jointly contribute to the development of cultural competence through Cultural Geography. Furthermore, relatively few studies have adopted mixed-methods designs that combine quantitative evidence of learning outcomes with qualitative analysis of students' learning experiences.

Although previous studies have demonstrated the educational benefits of project-based learning and digital technologies, little empirical evidence has examined their combined contribution to cultural competence development within Cultural Geography courses in higher education. Accordingly, the present study addresses this gap by investigating the effectiveness of a Cultural Geography course integrating project-based learning and digital technologies using a mixed-methods quasi-experimental design. By combining quantitative and qualitative evidence, the study seeks to provide a more comprehensive understanding of how competence-oriented geography education can support the development of university students' cultural competence.

Materials and methods

Research Design

This study employed a quasi-experimental research design using a pre-test–post-test control group approach to examine the effectiveness of a Cultural Geography course integrating project-based learning (PBL) and digital technologies in developing university students' cultural competence. A quasi-experimental design was selected because the participants were enrolled in existing academic groups, making random assignment impractical.

The study involved two groups. The experimental group participated in a redesigned Cultural Geography course that incorporated project-based learning activities and digital technologies, while the control group studied the same course using conventional lecture-based instruction and standard classroom activities. Both groups completed identical questionnaires before and after the instructional intervention.

The intervention was conducted over 15 weeks, with three academic hours of instruction per week, during the first semester of the academic year. The effectiveness of the instructional approach was evaluated by comparing pre-test and post-test results within and between the two groups.

The study adopted a mixed-methods approach by integrating quantitative and qualitative data. Quantitative findings from the quasi-experimental design were complemented by qualitative data obtained from students' reflective journals, classroom observations, and project reports to provide a more comprehensive understanding of the intervention outcomes.

This study adopted an explanatory sequential mixed-methods design, in which quantitative findings from the quasi-experimental phase were subsequently explained and enriched through qualitative analysis of reflective journals, classroom observations, and project reports.

Participants

The participants were 73 second-year undergraduate students enrolled in the Geography Teacher Education programme at Abai Kazakh National Pedagogical University, Kazakhstan. Participants ranged in age from 18 to 21 years and had successfully completed introductory Geography courses but had not previously studied Cultural Geography as a separate university course.

Because the study was conducted within an authentic educational setting, random assignment was not feasible. Instead, two existing academic classes were used. One intact class was designated as the experimental group ($n = 38$; 18 females and 20 males), while the other served as the control group ($n = 35$; 20 females and 15 males). Group allocation was established before the beginning of the semester according to the university timetable and was not influenced by the researchers.

All second-year students enrolled in the Cultural Geography course during the study period were invited to participate. Eligibility criteria included enrolment in the course, regular class attendance throughout the semester, and completion of both the pre-test and post-test questionnaires. No participants withdrew during the study, and complete datasets were obtained from all 73 students; therefore, no missing data treatment was required.

Both groups were taught by the same instructor over a 15-week semester (three academic hours per week) and followed the same Cultural Geography syllabus, learning objectives, assessment schedule, and contact hours. The only difference between the two groups was the instructional approach. The experimental group participated in project-based learning activities supported by digital technologies, whereas the control group received conventional lecture-based instruction and standard classroom activities. This design helped minimise potential instructor-related variation and ensured that differences in learning outcomes could be more confidently attributed to the instructional intervention.

Participation in the study was voluntary. Before data collection, all participants were informed about the purpose of the research and provided written informed consent. Participant anonymity and confidentiality were maintained throughout the study, and all collected data were anonymised before analysis.

The sample size was determined by the number of students enrolled in the Cultural Geography course during the study period. As the study employed intact academic classes in a quasi-experimental design, no additional sampling procedure was undertaken. Although no *a priori* statistical power analysis was performed, all eligible students available during the intervention were included in the study.

Before data collection, all participants received information about the purpose of the study, the voluntary nature of participation, confidentiality procedures, and their right to withdraw from the study at any stage without academic consequences. Written informed consent was obtained from all participants prior to participation. All data were anonymized before analysis and used solely for research purposes in accordance with the ethical principles of the Declaration of Helsinki.

Research Instruments

A researcher-developed questionnaire was designed to assess students' cultural competence in the context of the Cultural Geography course. The instrument was developed specifically for this study based on an extensive review of the literature on cultural competence, cultural geography education, project-based learning, and digital learning environments. The questionnaire consisted of 30 items organised into four dimensions: Cultural Knowledge (8 items), Cultural Sensitivity (7 items), Cultural Skills (8 items), and Cultural Interaction (7 items). Responses were measured using a five-point Likert scale ranging from

1 (strongly disagree) to 5 (strongly agree).

To establish content validity, the questionnaire was reviewed by two academic experts, including a professor specialising in Geography and a professor specialising in Pedagogy. Their recommendations were incorporated to improve the clarity, relevance, and comprehensiveness of the questionnaire before data collection.

The reliability of the instrument was assessed using Cronbach's alpha coefficient (Cronbach, 1951). The questionnaire demonstrated high internal consistency across all four dimensions: Cultural Knowledge ($\alpha = 0.887$), Cultural Sensitivity ($\alpha = 0.901$), Cultural Skills ($\alpha = 0.913$), and Cultural Interaction ($\alpha = 0.882$). The overall reliability coefficient for the 30-item questionnaire was $\alpha = 0.921$, indicating excellent internal consistency.

Construct validity was evaluated using Exploratory Factor Analysis (EFA). The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was 0.907, indicating excellent suitability for factor analysis. Bartlett's Test of Sphericity was statistically significant ($\chi^2(435) = 1248.56$, $p < .001$), confirming that the correlation matrix was appropriate for factor analysis and supporting the four-dimensional structure of the questionnaire.

In addition to the cultural competence questionnaire, students completed a separate five-item scale measuring the perceived pedagogical contribution of digital technologies. This scale was treated as an intervention-related outcome reflecting students' perceptions of the instructional approach rather than as a dimension of cultural competence. Therefore, pedagogical impact scores were analysed separately and were not included in the calculation of the overall cultural competence score.

Instructional Intervention

The instructional intervention was implemented over a 15-week semester, with three academic hours of instruction per week. Both the experimental and control groups studied the same Cultural Geography curriculum, covering identical learning objectives, thematic content, and assessment requirements. The same instructor taught both groups, ensuring consistency in course delivery, instructional time, and assessment procedures. The only difference between the two groups was the teaching approach adopted during the intervention.

The experimental group participated in a project-based learning (PBL) programme supported by digital technologies. Students worked collaboratively in small groups to investigate authentic cultural geography issues, including cultural landscapes, cultural heritage, regional identity, cultural diversity, and sustainable cultural development. Throughout the semester, students designed and implemented inquiry-based projects involving cultural mapping, spatial data analysis, field observations, collaborative discussions, digital storytelling, and project presentations. Each project required students to collect, analyse, and interpret cultural-geographical information before presenting evidence-based solutions to real-world cultural challenges.

To support project implementation, several digital technologies were integrated into the learning process. Geographic Information Systems (GIS) were used for spatial data analysis and digital cultural mapping. Cesium provided three-dimensional visualisation of cultural landscapes and heritage sites. Net-Logo enabled students to simulate cultural diffusion processes and explore spatial interaction patterns, while AnyLogic was employed to model human–environment relationships and population dynamics. Additional digital platforms were used for collaborative learning, presentation design, and reflective learning activities. These technologies encouraged active participation, collaborative inquiry, and the development of digital and spatial thinking skills.

In contrast, the control group received conventional lecture-based instruction following the standard university curriculum. Teaching methods primarily included lectures, textbook-based learning, teacher explanations, classroom discussions, and individual written assignments. Although both groups studied identical course content and were assessed using the same criteria, the control group did not participate in project-based learning activities or use the digital technologies incorporated into the experimental intervention.

Student learning was evaluated using identical assessment criteria in both groups to ensure comparability of learning outcomes. Assessment included project tasks, classroom participation, written assignments, presentations, and the pre-test and post-test cultural competence questionnaire. A detailed

description of the weekly instructional activities, project tasks, digital technologies employed, and assessment rubric is provided in Appendix A to facilitate replication of the intervention.

Data Collection Procedure

Data collection was conducted in three stages. During the first week of the semester, all participants completed the pre-test questionnaire to determine their initial level of cultural competence. Following the pre-test, the experimental group participated in the project-based learning intervention integrated with digital technologies, while the control group continued with conventional instruction over the 15-week semester.

At the end of the intervention, all participants completed the post-test questionnaire using the same instrument administered before the intervention. The collected data were anonymised and coded prior to statistical analysis to ensure confidentiality and accuracy.

Before data collection, all participants received information about the purpose of the study, the voluntary nature of participation, confidentiality procedures, and their right to withdraw from the study at any stage without academic consequences. Written informed consent was obtained from all participants prior to participation. All data were anonymized before analysis and used solely for research purposes in accordance with the ethical principles of the Declaration of Helsinki.

Data Analysis

The collected data were analysed using IBM SPSS Statistics (Version 27). Descriptive statistics, including means and standard deviations, were calculated to summarise students' performance before and after the intervention.

The reliability of the questionnaire was assessed using Cronbach's alpha coefficient, while construct validity was evaluated through Exploratory Factor Analysis (EFA), supported by the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity.

Prior to the intervention, independent-samples *t*-tests were conducted to examine baseline equivalence between the experimental and control groups. The effectiveness of the instructional intervention was then evaluated using mixed repeated-measures analysis of variance (ANOVA), with group (experimental vs. control) as the between-subjects factor and time (pre-test vs. post-test) as the within-subjects factor. This analysis was performed to determine whether changes in students' cultural competence over time differed significantly between the two groups.

Effect sizes were reported using partial eta squared (η^2) to assess the magnitude of the intervention effects. Statistical significance was established at $p < .05$.

Results

Baseline Comparison of the Study Groups

Before evaluating the effectiveness of the intervention, baseline equivalence between the control and experimental groups was assessed using independent-samples *t*-tests. As presented in Table 1, no statistically significant differences were observed between the two groups across any measured variable ($p > .05$). The control and experimental groups demonstrated comparable baseline levels of cultural knowledge, cultural sensitivity, cultural skills, cultural interaction, students' perceived pedagogical contribution of digital technologies, and overall cultural competence.

Because this study employed a quasi-experimental design using intact classes rather than random assignment, the absence of statistically significant baseline differences should not be interpreted as evidence of complete group equivalence. Therefore, the effectiveness of the intervention was evaluated primarily through mixed repeated-measures ANOVA, which directly examined changes over time between the two groups.

Table 1. Baseline comparison of cultural competence between the control and experimental groups

Outcome	Control (n = 35) Mean $\pm$ SD	Experimental (n = 38) Mean $\pm$ SD	p
Cultural knowledge	3.21 $\pm$ 0.54	3.25 $\pm$ 0.58	.731
Cultural sensitivity	3.34 $\pm$ 0.49	3.29 $\pm$ 0.52	.684
Cultural skills	3.17 $\pm$ 0.56	3.20 $\pm$ 0.51	.792
Cultural interaction	3.28 $\pm$ 0.53	3.31 $\pm$ 0.55	.765
Pedagogical impact of digital technologies	3.12 $\pm$ 0.61	3.15 $\pm$ 0.57	.814
Overall cultural competence	3.22 $\pm$ 0.48	3.24 $\pm$ 0.50	.756

Note. Independent-samples *t*-tests revealed no statistically significant baseline differences between the control and experimental groups across any outcome variable (all $p > .05$)

Effects of the Cultural Geography Intervention

To examine the effectiveness of the intervention, mixed repeated-measures ANOVA was conducted for each outcome variable. This analysis assessed whether changes in students' cultural competence over time differed between the control and experimental groups.

Descriptive statistics indicated improvements in both groups between the pre-test and post-test assessments; however, improvements were consistently greater in the experimental group. These descriptive trends were subsequently confirmed by the mixed repeated-measures ANOVA.

Mixed repeated-measures ANOVA demonstrated statistically significant Group $\times$ Time interaction effects for every measured outcome. Significant interaction effects were found for overall cultural competence ($F(1,71)=219.34$, $p<.001$, partial $\eta^2=.755$), cultural knowledge ($F(1,71)=568.46$, $p<.001$, partial $\eta^2=.889$), cultural sensitivity ($F(1,71)=139.44$, $p<.001$, partial $\eta^2=.663$), cultural skills ($F(1,71)=224.31$, $p<.001$, partial $\eta^2=.760$), cultural interaction ($F(1,71)=98.71$, $p<.001$, partial $\eta^2=.582$), and students' perceived pedagogical contribution of digital technologies ($F(1,71)=28.18$, $p<.001$, partial $\eta^2=.284$).

According to Cohen's (1988) guidelines, the interaction effects ranged from moderate to large, with the strongest effects observed for cultural knowledge, cultural skills, and overall cultural competence.

Table 2. Mixed repeated-measures ANOVA results for changes in cultural competence outcomes

Outcome	Control Pre	Control Post	Experimental Pre	Experimental Post	Group $\times$ Time F(1,71)	p	Partial η^2
Cultural knowledge	3.21 $\pm$ 0.54	3.38 $\pm$ 0.49	3.25 $\pm$ 0.58	4.32 $\pm$ 0.45	568.46	< .001	.889
Cultural sensitivity	3.34 $\pm$ 0.49	3.46 $\pm$ 0.47	3.29 $\pm$ 0.52	3.98 $\pm$ 0.48	139.44	< .001	.663
Cultural skills	3.17 $\pm$ 0.56	3.35 $\pm$ 0.51	3.20 $\pm$ 0.51	4.21 $\pm$ 0.43	224.31	< .001	.760
Cultural interaction	3.28 $\pm$ 0.53	3.44 $\pm$ 0.49	3.31 $\pm$ 0.55	4.15 $\pm$ 0.46	98.71	< .001	.582
Pedagogical impact of digital technologies	3.12 $\pm$ 0.61	3.29 $\pm$ 0.55	3.15 $\pm$ 0.57	4.41 $\pm$ 0.40	28.18	< .001	.284
Overall cultural competence	3.22 $\pm$ 0.48	3.38 $\pm$ 0.42	3.24 $\pm$ 0.50	4.21 $\pm$ 0.38	219.34	< .001	.755

Overall cultural competence

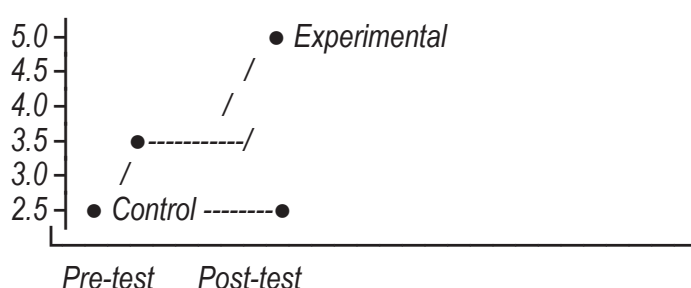


Figure 1. Estimated marginal means of overall cultural competence at pre-test and post-test (95% confidence intervals)

Changes in Individual Dimensions of Cultural Competence

To facilitate interpretation of the intervention effects, mean pre-post change scores (Δ) were calculated for each outcome variable (Table 3).

The experimental group demonstrated substantially greater improvements than the control group across all measured dimensions. The largest improvement was observed in students' perceived pedagogical contribution of digital technologies ($\Delta = 1.26$), followed by cultural knowledge ($\Delta = 1.07$) and cultural skills ($\Delta = 1.01$). Improvements were also evident for cultural interaction ($\Delta = 0.84$) and cultural sensitivity ($\Delta = 0.69$). In contrast, students in the control group demonstrated only modest improvements across all measured variables.

Overall cultural competence increased by 0.97 points in the experimental group compared with 0.16 points in the control group, corresponding to an additional improvement of 0.81 points following the intervention.

Table 3. Mean pre-post change (Δ) in cultural competence outcomes

Outcome	Control (Δ)	Experimental (Δ)	Difference
Cultural knowledge	0.17	1.07	0.90
Cultural sensitivity	0.12	0.69	0.57
Cultural skills	0.18	1.01	0.83
Cultural interaction	0.16	0.84	0.68
Students' perceived pedagogical contribution of digital technologies	0.17	1.26	1.09
Overall cultural competence	0.16	0.97	0.81

Note: Δ = Post-test mean – Pre-test mean

As shown in Table 3, the experimental group demonstrated greater improvements than the control group across every measured outcome. The largest between-group differences were observed for students' perceived pedagogical contribution of digital technologies and cultural knowledge, whereas the smallest difference was found for cultural sensitivity.

Qualitative Findings

Qualitative findings were used to support the interpretation of the quantitative results rather than to provide an in-depth qualitative evaluation of the intervention. Data collected from students' reflective journals, classroom observations, and project reports were analysed using thematic analysis following the six-phase approach proposed by Braun and Clarke (2006). The qualitative data were coded and analysed by the first author through repeated reading of the data, generation of initial codes, identification and refinement of themes, and review of thematic consistency. Four recurring themes were identified that complemented and explained the quantitative findings obtained from the mixed repeated-measures ANOVA.

Theme 1. Strengthening cultural knowledge through cultural mapping

Reflective journals and classroom observations indicated that cultural mapping activities enhanced students' understanding of cultural landscapes, sacred sites, and regional identities. Students demonstrated greater confidence in interpreting cultural phenomena using geographical concepts and spatial thinking. These observations are consistent with the substantial quantitative improvement observed in

cultural knowledge. One student noted, "Creating cultural maps helped me understand how cultural traditions are connected to geographical space" (Participant 12).

Theme 2. Digital technologies enhanced learning engagement

Students frequently described GIS applications, NetLogo, AnyLogic, and Cesium as valuable learning resources that supported the visualisation and interpretation of cultural phenomena. Classroom observations suggested that these technologies increased engagement, participation, and motivation throughout the learning process. These findings correspond with the improvement observed in students' perceived pedagogical contribution of digital technologies. As one participant reflected, "Using NetLogo and GIS made cultural processes easier to visualise and understand than traditional lectures" (Participant 21).

Theme 3. Project-based learning promoted cultural skills and interaction

Project-based learning encouraged collaboration, communication, and shared problem-solving. Students demonstrated greater confidence in collecting, analysing, organising, and presenting geographical information while working collaboratively with classmates. Classroom observations likewise indicated higher levels of participation and collaborative engagement. These findings support the quantitative improvements observed in cultural skills and cultural interaction. A student commented, "Working on projects with classmates improved my communication and teamwork skills" (Participant 8).

Theme 4. Increased cultural awareness and sensitivity

Reflective journals suggested that participation in the course increased students' awareness of Kazakhstan's cultural diversity, historical heritage, and regional traditions. Students also demonstrated greater appreciation of different cultural perspectives and recognised the importance of preserving cultural heritage. These observations complement the quantitative improvement identified in the cultural sensitivity dimension. One participant wrote, "The course helped me appreciate the cultural diversity of Kazakhstan from a geographical perspective" (Participant 15).

Integration of Quantitative and Qualitative Findings

The qualitative findings provided contextual explanations for the statistically significant improvements observed in the quantitative analyses. While the mixed repeated-measures ANOVA demonstrated significant Group $\times$ Time interaction effects across all measured dimensions, the qualitative evidence suggested that project-based learning, cultural mapping, collaborative learning, and digital technologies created meaningful learning experiences that supported the development of students' cultural competence.

The qualitative findings converged with the quantitative results by providing explanatory evidence for the statistically significant Group $\times$ Time interaction effects. Students consistently described how project-based learning, collaborative inquiry, cultural mapping, and digital technologies enhanced their understanding of cultural phenomena, strengthened cultural interaction, and increased engagement. Thus, the qualitative evidence supported the interpretation of the quantitative findings rather than serving as an independent source of theory generation.

Discussion

Interpretation of the Main Findings

The present study investigated whether integrating project-based learning (PBL) and digital technologies into a Cultural Geography course could enhance university students' cultural competence. The findings demonstrated that students who participated in the intervention achieved significantly greater improvements than those in the control group across all measured dimensions of cultural competence, including cultural knowledge, cultural sensitivity, cultural skills, and cultural interaction. Qualitative findings further indicated that project-based learning, cultural mapping, collaborative inquiry, and digital technologies created authentic learning experiences that strengthened students' engagement and supported the development of intercultural understanding. These findings reinforce the conceptualisation of cultural competence as a multidimensional construct comprising cognitive, affective, and behavioural dimensions that develop through meaningful educational experiences rather than through factual knowledge alone (Byram, 1997; Deardorff, 2006).

One explanation for these findings lies in the pedagogical characteristics of project-based learning. Rather than relying on teacher-centred instruction, students investigated authentic cultural-geographical

problems, analysed cultural landscapes, interpreted regional identities, produced digital cultural maps, and collaborated with peers throughout the semester. Such learning experiences encouraged active knowledge construction, reflection, communication, and collaborative problem-solving. These results are consistent with previous studies showing that project-based learning enhances higher-order thinking, collaboration, and authentic learning in higher education (Thomas, 2000; Bell, 2010). They also support Grobelski et al. (2023), who demonstrated that project-based geography education promotes geographical inquiry, collaborative learning, and intercultural understanding through authentic research activities.

The findings further highlight the educational value of Cultural Geography as a disciplinary context for competence-oriented learning. By examining relationships among culture, place, identity, and geographical space, students developed a deeper understanding of cultural diversity and the spatial processes shaping cultural landscapes. Unlike instructional approaches that address culture primarily from historical or sociological perspectives, Cultural Geography enables students to investigate cultural phenomena through spatial inquiry and geographical interpretation. These findings are consistent with previous work emphasising the contribution of Cultural Geography to understanding cultural landscapes, place identity, and spatial relationships (Morgan, 2001; Hall and Johnston-Anumonwo, 2016; Winders, 2014).

Digital technologies represented another essential component of the instructional intervention. The integration of GIS applications, NetLogo, AnyLogic, and Cesium enabled students to visualise cultural landscapes, construct digital cultural maps, simulate geographical processes, and analyse cultural phenomena from spatial perspectives. Rather than functioning solely as technological resources, these tools supported inquiry-based learning, collaborative investigation, and the development of spatial thinking. These findings are consistent with Kerski (2008), who emphasised the contribution of geospatial technologies to geographical inquiry, and with Wilensky and Rand (2015), who highlighted the educational value of modelling environments for analysing complex systems. They also align with recent empirical evidence showing that digital geospatial technologies improve students' spatial reasoning, collaborative inquiry, motivation, and disciplinary learning outcomes in higher education (Lee, 2023; Yan et al., 2023; Vojteková et al., 2023).

Finally, the findings support current international educational priorities that emphasise competence-oriented learning, intercultural understanding, and digital innovation. UNESCO (2021) identifies cultural diversity, global citizenship, and education for sustainable development as central goals of higher education, while the OECD Global Competence Framework (OECD, 2018) highlights learners' ability to understand multiple perspectives and engage constructively in culturally diverse societies. The instructional model examined in this study demonstrates how Cultural Geography, project-based learning, and digital technologies can be integrated to support these international educational priorities while providing an evidence-based approach for strengthening cultural competence among future geography teachers.

Practical Implications, Limitations, and Future Research Directions

The findings have several practical implications for geography teacher education and curriculum development. First, they suggest that Cultural Geography courses can extend beyond the transmission of disciplinary knowledge by incorporating authentic project-based activities that promote cultural competence alongside geographical understanding. Integrating project-based learning, cultural mapping, and digital technologies may simultaneously strengthen intercultural awareness, spatial reasoning, collaboration, communication, and problem-solving skills. These competencies are increasingly recognised as essential outcomes of higher education within international educational frameworks (UNESCO, 2021; OECD, 2018).

Second, the instructional approach presented in this study provides a practical model for curriculum innovation in geography education. Combining competence-oriented pedagogy with geospatial technologies may contribute to the modernisation of Cultural Geography curricula while supporting educational programmes related to cultural heritage, sustainability, and global citizenship. The proposed approach may also be valuable for teacher education programmes preparing future educators to work in culturally diverse learning environments.

Several limitations should be acknowledged. The study involved 73 students from a single university and employed a quasi-experimental design using intact classes; therefore, the findings should be interpreted cautiously and should not be generalised beyond similar educational contexts. Furthermore, the intervention lasted one academic semester, which may not have been sufficient for the long-term development of some dimensions of cultural competence, particularly cultural sensitivity and intercultural at-

itudes. Finally, because the study focused exclusively on Cultural Geography, further research is required before extending these findings to other academic disciplines.

Future research should investigate the effectiveness of this instructional approach across multiple universities, cultural contexts, and disciplinary settings. Longitudinal studies involving larger and more diverse samples would provide stronger evidence regarding the sustainability of competence development over time. Future investigations could also explore the educational potential of emerging technologies, including artificial intelligence, advanced Geographic Information Systems (GIS), immersive virtual environments, and digital mapping platforms, for supporting competence-oriented learning in geography education.

Conclusions

This study examined the effects of integrating project-based learning and digital technologies into a university Cultural Geography course on the development of students' cultural competence. The findings indicated that students who participated in the intervention demonstrated greater improvements in cultural knowledge, cultural sensitivity, cultural skills, and cultural interaction than those who received conventional instruction. The qualitative findings further suggested that project-based activities, cultural mapping, collaborative learning, and the use of digital technologies contributed to students' engagement and intercultural learning experiences.

The results suggest that combining project-based learning with digital technologies may provide an effective pedagogical approach for supporting competence-oriented learning in Cultural Geography. By engaging students in authentic geographical inquiry and collaborative problem-solving, the instructional approach created opportunities for connecting theoretical knowledge with real-world cultural contexts. These findings are consistent with current educational priorities that emphasise active learning, intercultural understanding, and the development of transferable competencies in higher education.

From a practical perspective, the study provides an example of how Cultural Geography courses may be redesigned to integrate project-based learning and digital technologies in ways that support students' cultural competence. The proposed instructional approach may also be relevant for curriculum development in geography teacher education and related fields that emphasise cultural diversity, sustainability, and global citizenship.

Several limitations should be acknowledged when interpreting these findings. The study was conducted with a relatively small sample from a single higher education institution using a quasi-experimental design over one academic semester. Therefore, the findings should be interpreted with caution and should not be generalised beyond similar educational contexts without additional empirical evidence.

Future research should examine the effectiveness of this instructional approach across different universities, cultural settings, and academic disciplines. Longitudinal studies involving larger and more diverse samples would provide a better understanding of the long-term development of cultural competence. In addition, future research could explore the potential of emerging technologies, including artificial intelligence, immersive virtual environments, and advanced geospatial tools, to further support competence-oriented learning in Cultural Geography.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The anonymized data supporting the findings of this study are available from the corresponding author upon reasonable request. For more information in this regard, please see:

https://www.ijcrsee.com/index.php/ijcrsee/journal_policies

Informed Consent Statement

Written informed consent was obtained from all participants involved in the study. Participants were informed that their participation was voluntary, that they could withdraw from the study at any time without penalty, and that their responses would remain anonymous and confidential

Institutional Review Board Statement

This study was conducted within the framework of routine educational practice at a higher education institution and involved minimal risk to participants. According to institutional regulations governing educational research, formal approval from an Institutional Review Board or Ethics Committee was not required. The research was conducted in accordance with the ethical principles of the Declaration of Helsinki. Participation was voluntary, all participants were informed about the purpose and procedures of the study before data collection, and written informed consent was obtained from each participant. Participant confidentiality and anonymity were maintained throughout the study, and all data were anonymized prior to analysis.

Author Contributions

Conceptualization, A.S. and K.K.; methodology, A.S. and K.K.; software, Z.M., I.K., and Y.S.; formal analysis, A.S. and A.B.; writing—original draft preparation, A.S., K.K., Z.M., I.K., A.B., and Y.S.; writing—review and editing, A.A., K.K., and Y.S. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Week-by-week instructional framework

Week	Topic	PBL Activity	Digital Tool	Learning Outcome
1	Introduction to Cultural Geography	Formation of project groups	Moodle	Understand course objectives
2	Cultural landscapes	Field observation	GIS	Identify cultural landscapes
3	Cultural mapping	Digital cultural map	ArcGIS/QGIS	Develop spatial thinking
4	Regional identity	Community investigation	Google Earth	Analyse regional identity
5	Cultural heritage	Photo documentation	Cesium	Visualise heritage sites
6	Cultural diffusion	Simulation	NetLogo	Model diffusion processes
7	Population and culture	Scenario modelling	AnyLogic	Analyse human-environment interaction
8	Interim project presentation	Peer feedback	Canva	Improve collaboration
9	Ethnocultural regions	GIS analysis	ArcGIS	Interpret spatial patterns
10	Sacred places	Field mapping	Cesium	Digital heritage representation
11	Cultural conflicts	Case study	NetLogo	Problem solving
12	Sustainable cultural development	Project work	GIS	Integrate SDGs
13	Digital storytelling	Video preparation	Canva	Communication skills
14	Final project	Presentation	PowerPoint	Project defence
15	Reflection and evaluation	Portfolio & reflection	LMS	Reflect on competence development

Table A2. Project assessment rubric

Criterion	Description	Weight (%)
Project quality	Completeness, organisation, and originality of the project	30
Cultural analysis	Accuracy and depth of cultural-geographical analysis	25
Use of digital technologies	Appropriate use of GIS, NetLogo, AnyLogic, Cesium, and other digital tools	20
Presentation	Clarity of oral presentation and visual communication	15
Reflection	Critical reflection on learning outcomes and cultural competence development	10
Total		100

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A New Scale in Education (Social Science)

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Abstract: This paper introduces a new scale in the social sciences that combines two types of measurements: a binary choice and a relative interval measurement consisting of 10+10 intervals. The scale's relative interval nature allows for differentiation between intervals of 10±10, expressed based on the principle of deciles. This approach provides a more nuanced differentiation between degrees compared to traditional Likert scales. The paper also discusses a coding method and includes graphical representations of the data. An important aspect of the scale is its capacity to categorize responses into positive and negative attitudes (NEGATT and POSATT), enabling separate descriptive and inferential statistical analyses.

Keywords: binary choice, intervals, measurements, new scale, social science.

Introduction - In memory of Rensis Likert, back in 1932

Social sciences, with their habitus and the complexity of the phenomena being investigated, are extremely complex in terms of the generalizations and assumptions that follow from research results. A series of challenges arise, such as the influence of several factors on the object of measurement (dependent/dependent variables) and the weak power of their control, the complexity/entanglement of the bio-psycho-social structure of a person and its manifest features in social phenomena and relationships, the problem of objectivity, bias, incoherence, implausibility, non-nomothetic, reliability, etc. From a methodological perspective, these challenges can make research in the social sciences uniquely complex. The lack of fundamental research is a key reason why social sciences lag behind medical, technical, and natural sciences, frequently struggling to keep pace with modern development trends. One could argue that social sciences are inherently challenging to explain objectively and reliably. Are they scientifically trustworthy? A significant advancement in establishing the scientific credibility of social sciences has been the development of a dominant scale for measuring attitudes: the Likert scale.

American social psychologist Rensis Likert, who was a faculty member at the University of Michigan from 1946 to 1970, developed a rating scale for measuring public attitudes toward international relations as part of his doctoral dissertation in 1932. The primary goal of this scale was to create a scientific method for assessing attitudes. Since its creation, the scale has garnered significant interest and has been applied in various scientific disciplines.

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An American doing business in China should be willing to abide by Chinese law.				
Strongly Approve (5)	Approve (4)	Undecided (3)	Disapprove (2)	Strongly Disapprove (1)
We should use military force in South America whenever needed to protect American investments.				
Strongly Approve (1)	Approve (2)	Undecided (3)	Disapprove (4)	Strongly Disapprove (5)

Figure 1. The original form of the Likert scale looks like this (Likert, 1932, p. 20)

Scholarly debate about the scale has continued for over half a century, with one of the key disputes being:

Is the Likert scale exclusively ordinal?

If it is exclusively ordinal, then we cannot use parametric, but exclusively non-parametric tests (Bishop and Herron, 2015). However, in the social sciences, we often use parametric tests on an ordinal type scale where they cannot be used. Accordingly, it is crucial to understand the implications of this mis-use, as it can lead to misleading results and interpretations. Researchers should be cautious and ensure they select the appropriate statistical methods that align with the scale of measurement to maintain the integrity of their findings. Accordingly, Jakobsson (2004) analyzed 166 full-length articles from the 2003 editions of *Cancer Nursing*, *Scandinavian Journal of Caring Sciences* and *Nursing*. Studies were reviewed for their use of ordinal data. The author concluded that ordinal scales were utilized in approximately one-third of the articles. However, only about half of the analyses of the ordinal data were conducted using the most appropriate statistical approaches (table 1).

Table 1. Ordinal data in the article (Ibidem, 438)

Journal	n	Appropriate presentation (%)	Appropriate analysis (%)
Cancer Nurs	17	53	38
Scand J Caring Sci	16	69	93
Nurs Res	18	28	38
Total	51	49	57

Although Jakobsson's (2004) study focused on medicine and nursing, a broader investigation in the social sciences could reveal interesting findings about authors' use of parametric tests on data collected using ordinal scales. This is because analyzing data collected on an ordinal scale using parametric tests is inappropriate (Pett, 1997; Lewis and Traill, 1999; Selimović, Opić and Selimović, 2023). On the other hand, Carifio and Perla (2007) discussed urban legends and ten myths about the Likert scale, providing logical counterarguments as antidotes. According to the authors, Myth 6 states that because the Likert scale is ordinal, only non-parametric tests can be used with it. They argue that this belief is incorrect, citing a Monte Carlo study that indicates that the F-test/ANOVA is highly robust even when the assumptions of using an interval scale are not met (Glass, Peckham, and Sanders, 1972). Supporting this interpretation is the viewpoint expressed by Harris (1975):

"A number of authors... have pointed out that statistical conclusions are valid whenever the distributions of numbers from which the data are sampled meet the assumptions (typically, normality and homogeneity of variance) used to derive the particular techniques being applied, irrespective of the measurement process which generated those numbers. Moreover, the validity of parametric statistics... is often affected very little by even relatively gross departures from these assumptions"

Allen and Seaman (2007) indicate that combining Likert scales into indices contributes to the value and variability of the data. In this case, if the assumption of normality of the distribution is met, parametric

statistics can be used. [Tanujaya, Prahmana, and Mumu \(2022\)](#) believe that the Likert scale becomes an interval scale when data generated are composite scores derived from multiple items. They also state that the Likert scale can also be used for parametric tests such as correlation, regression, z-test, t-test, ANOVA, Structural equation modeling, and Factor analysis (also sum, mean, and standard deviation) (p. 97). [Guerra, Gidel, and Vezzetti \(2016\)](#) avoid giving a definitive answer to whether parametric tests can be applied to Likert scale data, referencing [Adams, Fagot, and Robinson \(1965\)](#):

“Nothing is wrong per se in applying any statistical operation to measurements of given scale, but what may be wrong, depending on what is said about the results of these applications, is that the statement about them will not be empirically meaningful or else that it is not scientifically significant” (p. 100).

What is the optimal number of points on a Likert scale?

The five-point Likert scale is the most commonly used, but there are varying opinions on the advantages and disadvantages of the number of categories or levels in the scale. According to [Yaska and Nuhu \(2024\)](#), who analyzed measures of central tendency and variability, the 5-point Likert scale is the optimal choice when compared to a 4-point Likert scale. [Chang \(1994\)](#) compared the validity and reliability of 4-point and 6-point Likert scales. In an empirical approach, different measurement models were fit by confirmatory factor analyzes of a multitrait-multimethod covariance matrix. The results showed lower reliability (heterotrait-monomethod coefficients) with the 6-point scale than with the 4-point scale, but when it comes to validity, there was no difference between the 4-point and 6-point scales.

Conjunction results of research on the influence of the number of scale points on measurement capabilities (reliability) are contradictory. For example, [Brown, Widing and Coulter \(1991\)](#) analyze the SOCO scale and conclude that “(...) the reduction in scale points and accompanying anchors did not lead to any reduction in the scale’s measurement capabilities” (p. 350).

Research shows similar results about how the number of scale levels does not substantially affect psychometric properties (reliability, validity): [Finstad \(2010\)](#), [Nunnally and Bernstein, \(1994\)](#). However, [McCallum, Keith and Wiebe \(1988\)](#), [Boote \(1981\)](#), [Hernández, Muñiz and García Cueto \(2000\)](#), [Moreno, Martínez and Muñiz \(2004\)](#), [Muñiz, García-Cueto and Lozano \(2005\)](#) show the opposite, that is, how the number of levels (points) on a scale affects psychometric properties. [Lozano, García-Cueto, and Muñiz \(2008\)](#) found that increasing the number of points on a scale enhances both validity and reliability. They observed that when a scale has fewer than four points, both reliability and validity tend to decrease. The authors concluded that while increasing the scale beyond seven points does not significantly improve validity and reliability, the optimal number of response options lies between four and seven. [Leung \(2011\)](#) investigated some psychometric properties of 4,5,6, and 11-point Likert scales on a sample of 1217 students in Macau. There were no significant differences found in the internal structure regarding means, standard deviations, item-item correlations, item-total correlations, Cronbach’s alpha, or factor loadings. The results suggest that increasing the number of scale points helps reduce skewness, with the 11-point scale (ranging from 0 to 10) showing the lowest kurtosis and being closest to a normal distribution. Only the 6- and 11-point scales align with normal distributions based on Kolmogorov-Smirnov and Shapiro-Wilk tests. The findings on predictive validity are inconclusive. This article recommends adopting an 11-point scale, as it enhances sensitivity and approximates interval-level measurement and normality.

The optimal number of categories on the Likert scale in the literature varies. It ranges from the dichotomous feature (2) to 3 categories, then 4 with the argument of avoiding anchoring neutral values (or without it), 5 (the most common category in social sciences), 6, 7, 9, 11 categories, and more. Moreover, [Garner \(1960\)](#) concludes that “ information transmission measures, after correction for sampling bias, show a small but definite increase in discrimination up to the 20 categories used” (p 352).

An intriguing research study by [Miller \(1994\)](#) demonstrates:

“What about the magical number seven? What about the seven wonders of the world, the seven seas, the seven deadly sins, the seven daughters of Atlas in the Pleiades, the seven ages of man, the seven levels of hell, the seven primary colors, the seven notes of the musical scale, and the seven days of the week? What about the seven-point rating scale, the seven categories for absolute judgment, the seven objects in the span of attention, and the seven digits in the span of immediate memory? For the present, I propose to withhold judgment. Perhaps there is something deep and profound behind all these

sevens, something just calling out for us to discover it. But I suspect that it is only a pernicious, Pythagorean coincidence" (p. 351).

The author suggests, albeit in a poetic manner, that a scale of 7 points, with a margin of plus or minus two, is optimal. Additionally, the findings of [Green and Rao \(1970\)](#) indicate that expanding the scale beyond 7 points (response categories) is unnecessary.

[Preston and Colman \(2000\)](#) examine the reliability, validity, and discriminative power of various point scales. The results showed that scales with two, three, and four response categories performed poorly across various indices of reliability, validity, and discriminating power. In contrast, scales with more categories, up to seven, showed significantly better results. While internal consistency remained similar across all scales, test-retest reliability tended to decrease for scales with more than 10 response categories. Respondents expressed the highest preference for the 10-point scale, followed closely by the 7-point and 9-point scales.

[Schrum, Johnson, Ghuy, Gombolay \(2002\)](#) suggest a scale of 5-9 points as a rule of thumb; less than 5 or more than 9 points cause a lack of precision. [Aybek and Toraman \(2022\)](#) compare 3-point, 5-point, and 7-point Likert scales. They conclude that the 5-point scale provides greater reliability than the 3-point scale, while there is no significant difference in reliability between the 5-point and 7-point scales. Therefore, they recommend using the 5-point scale as the best option. [De Vellis \(2003\)](#) states that a scale with a neutral value can lead to ambiguity in the interpretation of data (strongly disagree, disagree, *somewhat disagree*, *somewhat agree*, agree, and strongly agree). The authors [Pearson, Lacombe and Khatun \(2024\)](#) conclude the opposite, outlining that overlooking/ignoring a "neutral" category can result in flawed inferences, which can impede the advancement of personal finance research (can lead to biased estimates).

Increasing the number of points on a scale can lead to greater variability, particularly in small sample sizes. This may violate the assumptions of a normal distribution (such as the coefficient of variability) and can also impact the asymmetry of sampling distributions. While a higher number of scale points does not always lead to increased variability, especially when respondents' attitudes are highly polarized, it can result in a U-shaped distribution. Another significant issue with expanding the Likert scale is that it becomes difficult for individuals to clearly distinguish between certain points or categories in a semantic context. As the number of scale points increases, cognitive differentiation becomes problematic.

The limitations of the Likert scale can be summarized as follows ([Jamieson, 2000](#)):

1. The response categories in Likert scales are ordered, but the intervals between the values should not be assumed to be equal.
2. A Likert scale is inappropriate for parametric tests (based on the mean and variance/standard deviation).
3. Treating ordinal scales as interval scales can be very controversial.
4. It has become a common practice to treat Likert-type categories as if they represent interval-level measurement.

We can also expand this to:

5. Giving socially desirable answers (especially when it comes to semantic categories).
6. Tending to give middle/neutral values (if the number of degrees on the scale is odd, id est. if it has a neutral value - the midpoint of "neither agree nor disagree"([Chyung et al., 2017](#))).
7. Confusing semantic differences of opposing categories (e.g., category 2 – I partially disagree vs category 4 – I partially agree). Statistically, it is a huge difference, but in a normative linguistic statement, this is almost the same, because if I partially agree then I also partially disagree. How much is partially positive greater than partially negative?
8. Unnecessary avoidance of non-parametric statistics - avoidance of categorical dichotomous/ trichotomous/ polytomous variables (not rank). In medicine, for example using procedures like Odds ratio, probability, Log Logistic, Cox, Logit, and probit regression... gives extremely useful data/predictions (compared to survival analysis Kaplan Meier...)

One of the challenges of the Likert scale is bias. When the variables are in the format of positive answers, it is possible to expect a bias towards positive preferences. Then, the negation concept is often introduced with the aim of bias control. However, this can be counterintuitive, as it requires greater cognitive engagement and can lead to an increase in errors. One solution, according to [Friborg Martinussen](#)

and Roseninge (2006), is to use Osgood's Semantic differential (1952). The authors compare the Likert scale and the semantic differential on a sample of 334 students and conclude that the semantic differential affects the reduction of bias, i.e. there was a reduction in variance, internal consistency, and a better factor structure was obtained in the case of using the semantic differential (at the same time, there was no lowering of psychometric quality). However, the Semantic Differential cannot be considered a Likert scale because it uses bipolar antonyms (Verhagen, van den Hooff and Meents, 2015).

Uebersax (2006) elaborates on the most common mistakes in the use of the Likert scale and states the problematic nature of defining the Likert scale (e.g., when a scientist says that he used a Likert scale, it is not clear what is meant by that term). The author states that the Likert scale never refers to a separate variable but to a set of several variables whose responses are added together and give an average total result on the subject of measurement. Additionally, Uebersax (2006) postulates that a rating scale producing ordered category data (e.g., How often do you smoke cigarettes? 1. Never; 2. Once in a while; 3. 1-5 cigarettes per day; 4. More than 5 per day) is not a Likert scale. One of the ways to overcome the problem of the Likert scale is, according to Anjaria (2022), deploying the Z-number in conjunction with the Likert scale. The author introduces an algorithm for deriving Z-numbers from Likert scale data. It also explains how these concepts can be applied to convert Likert scale responses into Z-numbers.

Presentation of a new scale in social sciences

The scale consists of two levels. The first level is a binary outcome (dichotomous) where the respondent circles agree/disagree, or yes/no. The second level consists of the respondent assessing the intensity of the binary choice on a 10+10 point scale, expressed on the principle of deciles. The scale diagram is presented in Figure 2.

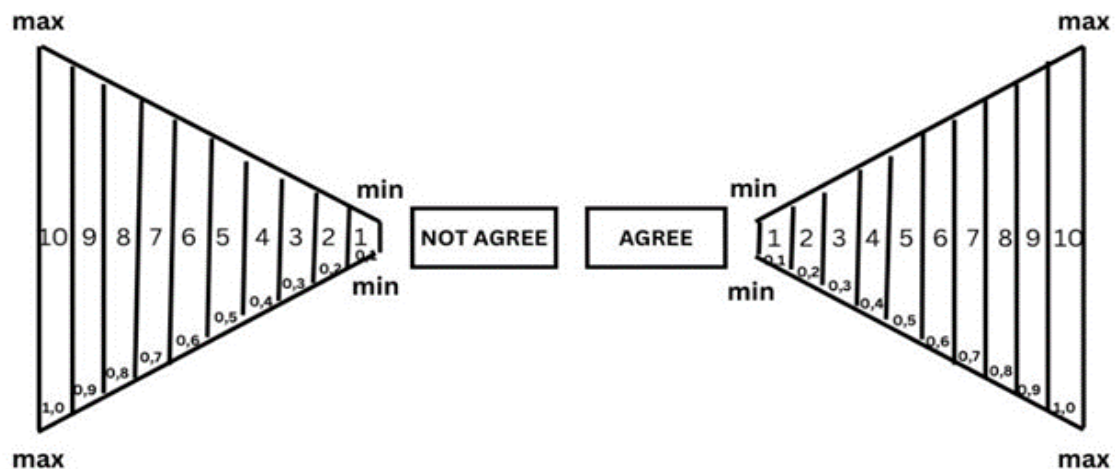


Figure 2. Binary-relative interval scale

The scale comprises a total of 20 intervals: 10 associated with the option "NOT AGREE" and 10 with the option "AGREE." Unlike traditional Likert scales, this scale does not include a neutral midpoint, as respondents do not have the option to indicate that they neither agree nor disagree.

However, a midpoint does statistically exist. For example, if the frequencies for the "NOT AGREE" and "AGREE" intervals are equal, the mean, mode, and median (MCT) would all equal 2, indicating a balanced position. In this scenario, a value of 2 suggests a state of ambivalence, reflecting both agreement and disagreement, thus representing an absence of a definitive positive or negative attitude.

The coding of the scale involves subtracting 2 for each instance marked as "Not AGREE" and adding 2 for each instance marked as "AGREE." This process can be represented as follows: for each marked

value of intensity “Not AGREE,” we use $x - 2$, and for each marked value of intensity “AGREE,” we use $x + 2$. The graphical representation of this coding is illustrated in Table 2.

Table 2. Coding scale

	Not agree (NEGATT)										Agree (POSATT)									
X Initial scale values	1	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
	2-(x)										2+x									
Coded values	1	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,1	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3

After coding, we got a rating scale from 1.0 to 3.0. The interpretation of the numerical values on the scale represents the intensity of the attitude (figure 3).

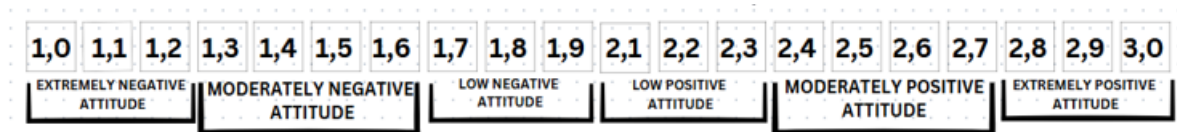


Figure 3. Intensity of the attitude

The new scale does not have an explicitly defined neutral value. However, we can determine a neutral value by calculating a measure of central tendency, such as the mean. For instance, if respondents have the same frequency across all intervals (degrees), for example, $f(1)=1$, $f(1.1)=1$, $f(1.2)=1$, $f(1.3)=1$, and so on until $f(3)=1$, then the mean would equal 2.00. In this scenario, the median would also be 2, and the skewness would be 0, indicating a neutral attitude. Statistically, values within the range $1,9 \leq x \leq 2,1$ indicate a neutral midpoint, representing the absence of a specific attitude neither positive nor negative (see figure 4).

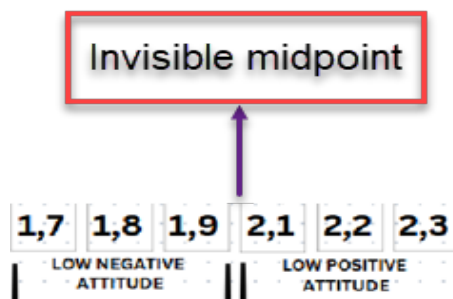


Figure 4. Invisible midpoint of scale

Advantages of the scale

In contrast to a regular Likert scale, our proposed scale has several advantages including:

1. Generating a binary outcome (discrete) in a form (yes-no, agree-not agree) suitable prior for non-parametric tests/approaches (e. g. logit and probit regression, Bayesian inference, Fisher's exact test, descriptive statistics for binary data, Log-linear...). Binary variables are cost-effective, easier to understand and interpret, and require less cognitive effort. They simplify decision-making and are less influenced by cultural differences that can arise when using a scale with multiple degrees of agreement or disagreement. Additionally, the binary choice format (such as agree/disagree or yes/no) promotes simplicity and helps streamline generalizations.
2. Existence of double measurement: binary outcomes (agree/not agree; yes/no) and additional relative interval measurement as extended measurement. The assumption is that respondents can relatively well distinguish 10 degrees (intervals), the intensity of agreement (disagreement) with a certain statement. The new scale is based on 10 relatively identical intervals that represent centiles, and it is easier for the respondent to distinguish the intensity on a scale up to 10 than, for example,

to 7 or 8. It is better and more precise to distinguish using 10 parts (deciles) because it is based on tens (10,20,30...). No, of course, this is conditional and the term relatively interval scale is used. Introduction of 10 intervals (deciles) separately for negative and positive attitude of impact on measurement precision. For example, Figure 5 shows the graphical distribution of responses to variable V1 (empirical part) using the Likert scale and the new scale. The introduction of 10 intervals (deciles) for both negative and positive attitudes improve the precision of measurement. For instance, Figure 4 illustrates the graphical distribution of responses to variable V1 (empirical part) using both the Likert scale and the new scale.

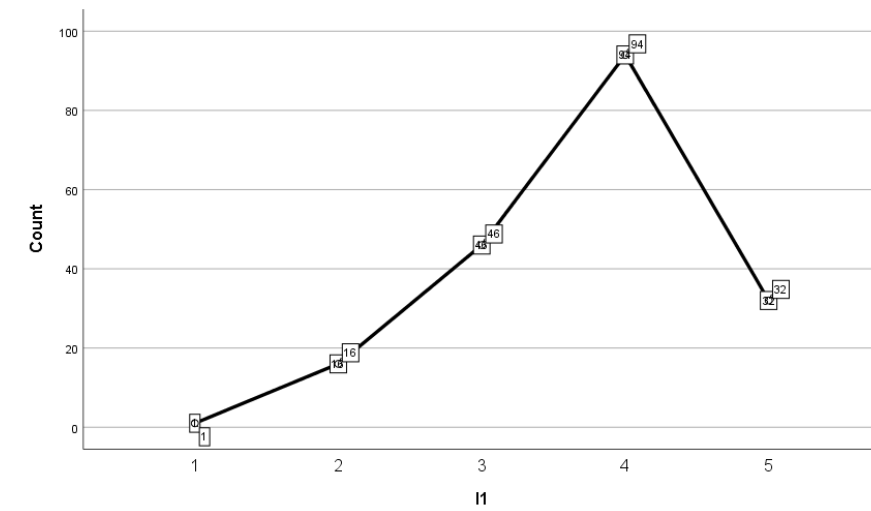


Figure 5a. Likert

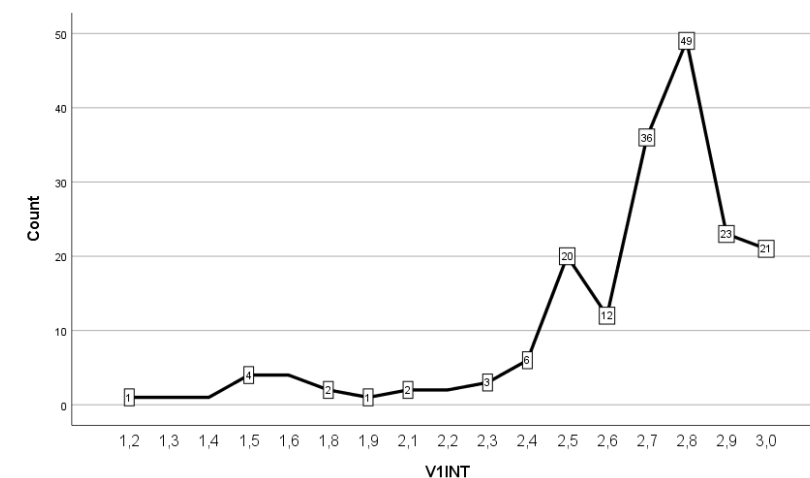


Figure 5b. New scale

Figure 5a (Likert scale responses) illustrates the distribution of responses to variable I1. The results indicate that: 1 respondent completely disagrees, 16 respondents partially disagree, 46 respondents neither agree nor disagree, 94 respondents partially agree, and 32 respondents fully agree with the statement: "In most ways, my life is close to my ideal." The distribution of responses for the same variable on the new scale involving the same respondents, is presented in Table 3.

Table 3. Distribution of variable V1INT (new scale)

Value	f	INTENSITY of attitude
1,0-1,2	1	Extremely negative attitude
1,3-1,6	10	Moderately negative attitude
1,7-1,9	3	Low negative attitude
2,1-2,3	7	Low positive attitude
2,4-2,7	74	Moderately positive attitude
2,8-3,0	93	Extremely positive attitude

In this example, the improved precision of the measurement is evident. On the Likert scale, 46 subjects reported a neutral value of 3, which is not reflected in the new scale. For the variable I1 (Likert), the arithmetic mean is 3.7. On a 5-point scale, this value can be challenging to interpret regarding intensity; instead, measures such as mode or median may be more appropriate. In contrast, the new scale yields a mean of 2.6, which accurately represents a real value, id est. a *moderately positive attitude* within the statistical set. However, it's important to note that the larger range of intervals on the new scale can result in extreme values that distort the arithmetic mean. Therefore, the new scale is recommended, particularly when dealing with large sample sizes.

3. The scale values, after coding, are expressed with one decimal place, enhancing the precision of the measurement.

1	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,1	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3
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The proposed scale enhances the accuracy of descriptive statistics, as the calculated arithmetic means reflect actual values on the scale, rounded to one decimal place. For instance, if the mean is 1.63 (NEGATT), the value 1.6 is a valid point on the scale, meaning the mean is a real, measurable value rather than an abstract one.

4. The ability to perform differential statistical presentation and analysis for each binary choice 'Not agree' (NEGATT for negative attitude) or 'I agree' (POSATT for positive attitude), as illustrated in Figure 6.

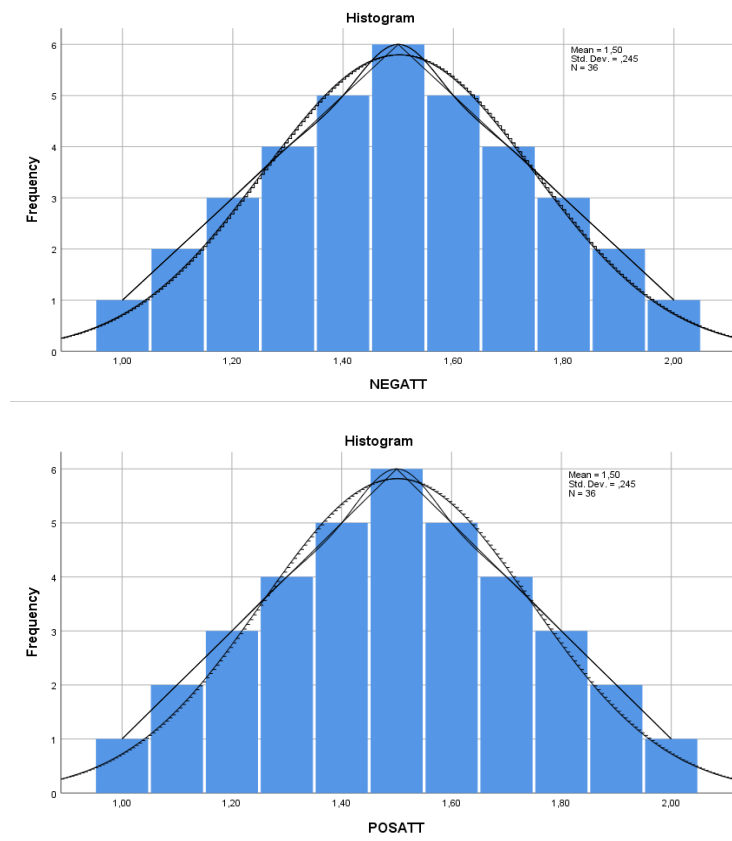


Figure 6. Distribution (normal) for NEGATT and POSATT

5. The invisible midpoint occurs between the ranges of NEGATT (0.1-1, coded 1-1.9) and POSATT (0.1-1, coded 2.1-3), with the coded value 2 representing the invisible midpoint
6. The probability of missing responses is reduced because the respondent is presented with a clear binary choice, unlike in the Likert scale. This binary format requires less cognitive effort from the respondent.

Empirical part

To gain insight into the descriptive characteristics of the new scale, a study on life satisfaction was conducted with a sample of 190 students at the University of Zagreb. The respondents completed a modified version of the Satisfaction with Life Scale (SWLS) using a 5-point Likert-type scale. They then re-evaluated their level of agreement with the same variables, this time using the new scale, which included a total of 12 variables.

The descriptive characteristics of all 12 variables on the new scale show that the coefficient of variation (CV) is lower than that of the Likert scale. This indicates better consistency and less variability, meaning that the mean is a more accurate representation of the actual values. Additionally, the standard errors of the arithmetic means are smaller, suggesting that the sample means more accurately reflect the population values. As a result, the confidence intervals are narrower due to the smaller standard error (SE), leading to greater certainty about the estimates. Similarly, a reduction in the standard error enhances the power of the statistical tests, thereby decreasing the likelihood of a Type II error. Moreover, the arithmetic mean values represent the actual values (to one decimal place), which is often not the case with the Likert scale. Although the values of skewness and kurtosis are higher, they remain within the acceptable limits according to Kline (2016).

Table 4. Descriptive values of Likert scale and new scale

	Range	Minimum	Maximum	Mean	Std. Deviation	Coefficient of variation	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Skewness
I1	4	1	5	3,74	,062	,858	0,23
V1INT	1,8	1,2	3,0	2,64	,0265	,3629	0,14
I2	4	1	5	4,29	,061	,840	0,20
V2INT	1,8	1,2	3,0	2,70	,0244	,3351	0,12
I3	3	2	5	4,24	,057	,776	0,18
V3INT	1,7	1,3	3,0	2,74	,0218	,2988	0,11
I4	3	2	5	4,09	,061	,836	0,20
V4INT	1,7	1,3	3,0	2,68	,0239	,3282	0,12
I5	4	1	5	3,50	,090	1,236	0,35
V5INT	2,0	1,0	3,0	2,42	,0432	,5914	0,24
I6	4	1	5	4,07	,068	,934	0,23
V6INT	1,9	1,1	3,0	2,68	,0286	,3917	0,15
I7	4	1	5	3,72	,073	1,003	0,27
V7INT	2,0	1,0	3,0	2,53	,0353	,4842	0,19
I8 (recoded)	4	1	5	3,53	,090	1,231	0,35
V8INT (recoded)	2,0	1,0	3,0	2,23	,0489	,6689	0,30
I9	4	1	5	3,44	,075	1,035	0,30
V9INT	2,0	1,0	3,0	2,36	,0420	,5730	0,20
I10	3	2	5	3,98	,059	,807	0,20
V10INT	1,7	1,3	3,0	2,62	,0265	,3616	0,14
I11	4	1	5	3,18	,073	1,008	0,32
V11INT	2,0	1,0	3,0	2,18	,0434	,5914	0,27
I12	4	1	5	2,84	,087	1,203	0,42
V12INT	2,0	1,0	3,0	1,99	,0517	,7068	0,36

V1(I1) In most ways, my life is close to my ideal; V2(I2) The conditions of my life are excellent; V3(I3) I am satisfied with my life; V4(I4) So far I have gotten the important things I want in life; V5(I5) If I could live my life over, I would change almost nothing; V6(I6) When I watch others live, I feel satisfied; V7(I7) I am satisfied with my appearance; V8(I8) I would be more open to living in a different part of the world; V9(I9) I am happy with my finances; V10(I10) A bright future awaits me; V11(I11) The educators' salary will be enough for me to have a comfortable and happy life; V12(I12) I am satisfied with the position of teacher/ educator in society.

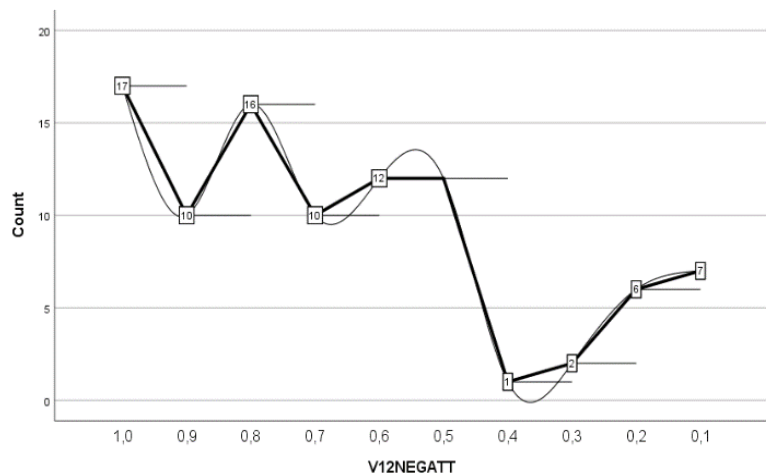
The new scale also presents more accurate, precise quantiles (quartiles, deciles) which results in better interpolation. Table 5 shows the quantile values for the Likert and new scales.

Table 5. Descriptive values of scales

		New scale												Likert											
		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12
Percentiles	10	2,29	2,30	2,40	2,39	1,48	2,28	1,60	1,00	1,50	2,10	1,27	1,10	3,00	3,00	3,00	3,00	2,00	3,00	2,00	1,00	2,00	3,00	2,00	1,00
	20	2,50	2,50	2,60	2,50	1,70	2,50	2,30	1,10	1,70	2,50	1,50	1,20	3,00	4,00	4,00	3,00	2,00	3,00	3,00	1,00	3,00	3,00	2,00	2,00
	25 q1	2,52	2,60	2,70	2,60	1,90	2,60	2,40	1,10	1,90	2,50	1,60	1,30	3,00	4,00	4,00	4,00	3,00	3,00	3,00	1,00	3,00	3,00	3,00	2,00
	30	2,60	2,70	2,70	2,60	2,24	2,60	2,50	1,20	2,30	2,50	1,71	1,40	3,00	4,00	4,00	4,00	3,00	4,00	3,00	2,00	3,00	4,00	3,00	2,00
	40	2,70	2,70	2,80	2,70	2,50	2,70	2,60	1,40	2,48	2,60	2,20	1,50	4,00	4,00	4,00	4,00	3,00	4,00	4,00	2,00	3,00	4,00	3,00	2,00
	50	2,70	2,80	2,80	2,80	2,60	2,80	2,70	1,50	2,60	2,70	2,35	2,10	4,00	4,00	4,00	4,00	4,00	4,00	4,00	2,00	4,00	4,00	3,00	3,00
	60	2,80	2,90	2,90	2,80	2,80	2,90	2,74	1,90	2,70	2,80	2,50	2,40	4,00	5,00	5,00	4,00	4,00	4,00	4,00	3,00	4,00	4,00	3,00	3,00
	70	2,80	2,90	2,90	2,90	2,90	2,90	2,80	2,30	2,79	2,80	2,60	2,60	4,00	5,00	5,00	5,00	4,00	5,00	4,00	3,00	4,00	4,00	4,00	3,00
	75 q3	2,80	2,90	2,90	2,90	2,90	3,00	2,90	2,50	2,80	2,90	2,70	2,70	4,00	5,00	5,00	5,00	5,00	5,00	4,00	3,00	4,00	5,00	4,00	4,00
	80	2,90	3,00	2,90	2,90	3,00	3,00	2,90	2,50	2,80	2,90	2,70	2,74	4,00	5,00	5,00	5,00	5,00	5,00	5,00	4,00	4,00	5,00	4,00	4,00
90	3,00	3,00	3,00	3,00	3,00	3,00	3,00	2,70	3,00	3,00	2,80	2,90	5,00	5,00	5,00	5,00	5,00	5,00	5,00	4,00	5,00	5,00	4,00	5,00	

In terms of reliability testing, the new scale demonstrated greater reliability, with a Cronbach's alpha of 0.804, compared to $\alpha=0.787$ for the Likert scale. Additionally, the Intraclass Correlation Coefficient (ICC) was also higher for the new scale (0.804) than for the Likert scale (0.787).

One of the key advantages of this scale is that it allows for the division of attitudes into positive (POSATT) and negative (NEGATT) categories. This setup facilitates a detailed analysis of the intensity of both positive and negative attitudes, rated on a scale from 1 to 10. Additionally, descriptive statistics can be calculated separately for each category and compared against one another. This approach is especially useful in economic research, where understanding the intensity of separate attitudes, both positive and negative, is critical. For instance, in our example referenced as V12INT, respondents are polarized regarding their satisfaction with the position of teachers and educators in society, with a mean score of 1.99, a minimum of 1, and a maximum of 3. This distribution is not normal. By separating respondents into POSATT and NEGATT categories, we gain better insight into the nuances of their satisfaction and dissatisfaction levels. The binary choice data also reveal that 49.7% of respondents are dissatisfied (do not agree) with the position of teachers and educators in society, while 50.3% are satisfied (agree). In Figures 7a and 7b, the variable V12INT is displayed, highlighting the separate NEGATT and POSATT groups.



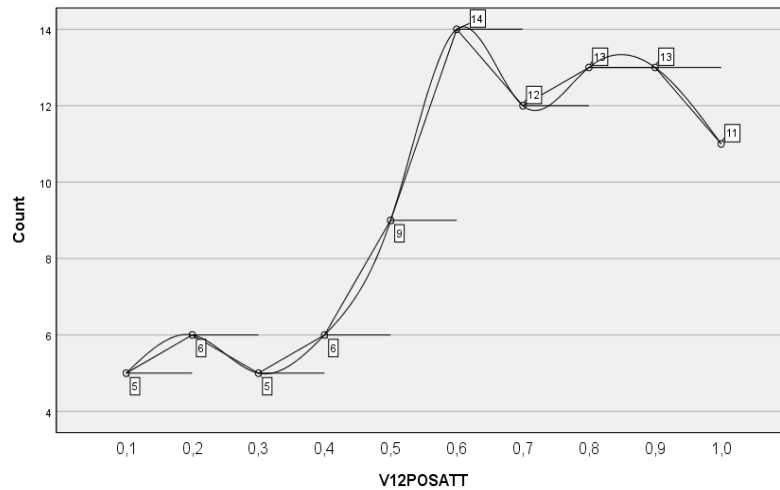


Figure 7a & 7b. NEGATT & POSSAT

Figure 7a illustrates the distribution of the NEGATT variable (V12). For instance, 16 respondents expressed a disagreement intensity of 8 out of 10 regarding the statement associated with the variable (V12), while 6 respondents indicated a disagreement intensity of only 2 out of 10 (as shown in Figure 7a). In comparison, the POSATT variable in Figure 7b shows that 14 respondents agreed with the statement at an intensity of 6 out of 10, and 11 respondents showed maximum agreement with a rating of 10 out of 10. This indicates that they are extremely satisfied with the role of teachers and educators in society (see Figure 7b).

In the case of separating respondents into POSATT and NEGATT for a certain variable(s), we can compare them separately, display descriptive characteristics, calculate the values of MCT, MV, specificities of sampling distributions, and use statistical tests to test differences and relationships between subsamples (POSATT and NEGATT). Although the sampling distribution of the variable deviates significantly from the normal distribution (attitudes are polarized), separating the distribution of the variable into NEGATT and POSATT provides the possibility of separate distributions, in this case significantly closer to the normal distribution; p-p plot (figures 8a, b, c).

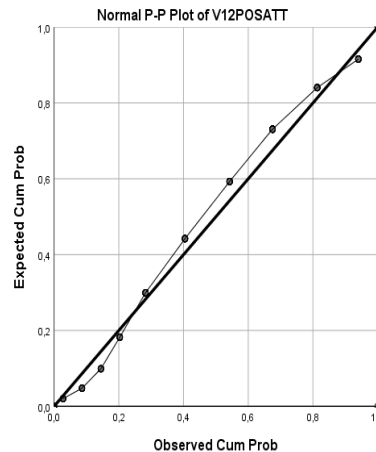


Figure 8a. P-P plot POSATT V12INT

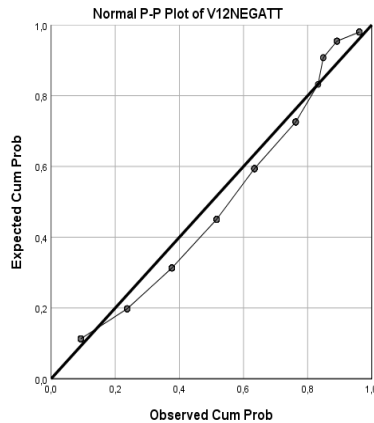


Figure 8b. P-P plot NEGATT V12INT

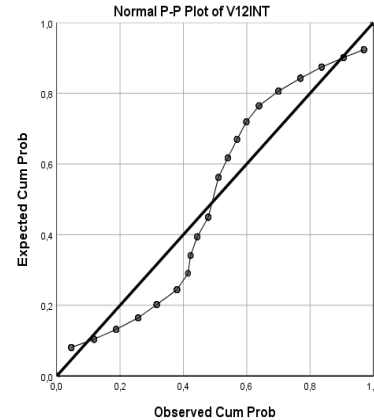


Figure 8c. P-P plot V12INT

The introduction of a new scale that includes binary choices is a valuable enhancement, as it allows for prior non-parametric analysis. In the area of predictive role testing, the new scale has the a priori option of using binary choice (as a DV) for nonlinear regression; e.g., logistic regression, Probit, Cox PHR..., and also as an additional relative interval measurement and the possibility of using linear regressions (nonlinear, too). Binary choice scales are extremely useful in a predictive sense and are often used in medicine, technical sciences. For example, binary choice V7 shows a graph of predicted probability for the variable age* V7 (figure 9).

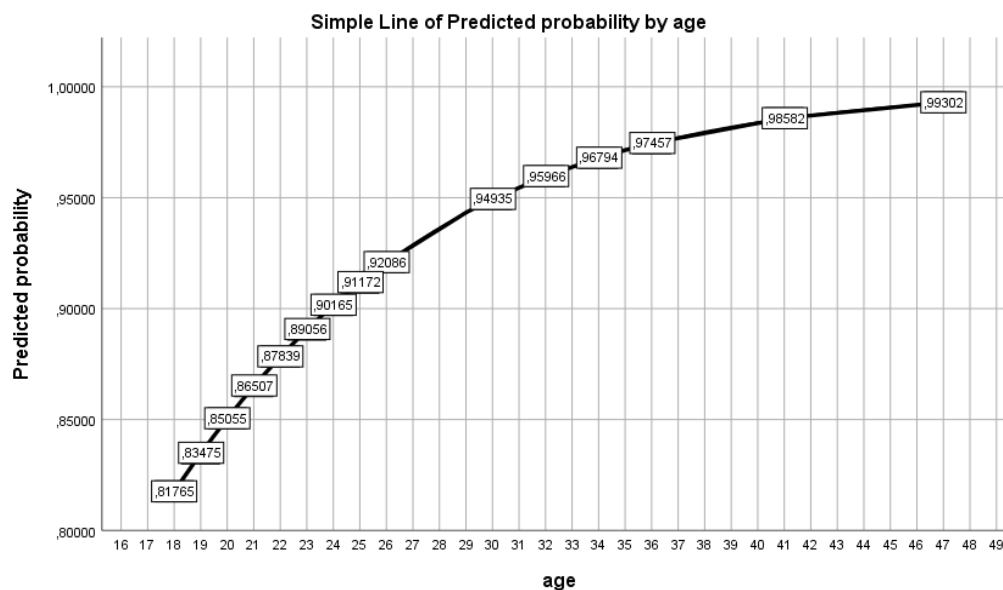


Figure 9. Predicted probability

The probability of students aged 20 in the sample being satisfied with their appearance is 83%, while for students aged 41 who are part-time students, the satisfaction rate is as high as 98%. Predicted probabilities (log-odds, odds, and probabilities) provide extremely valuable statistical data and should be utilized more in social science research. However, when using a 5-point Likert scale, the neutral value (3) complicates the ability to make a binary choice.

The new scale, which considers an interval range of 10+10, allows for the development of more complex regression models. However, this complexity can lead to issues such as overfitting or the misinterpretation of non-linear relationships between variables. Despite these potential challenges, this scale yields more accurate predictive results than the Likert scale. For instance, the interpretations of beta values are more precise, and also standardized regression residuals (see Figure 10a, b), which can also influence other regression parameters.

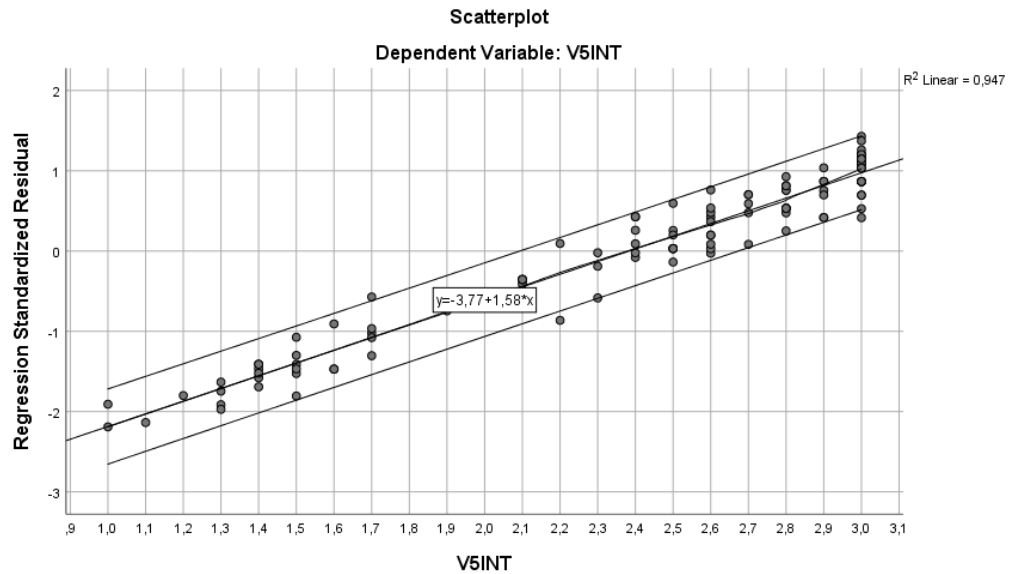


Figure 10a. RSR V5*academic grade (New scale)

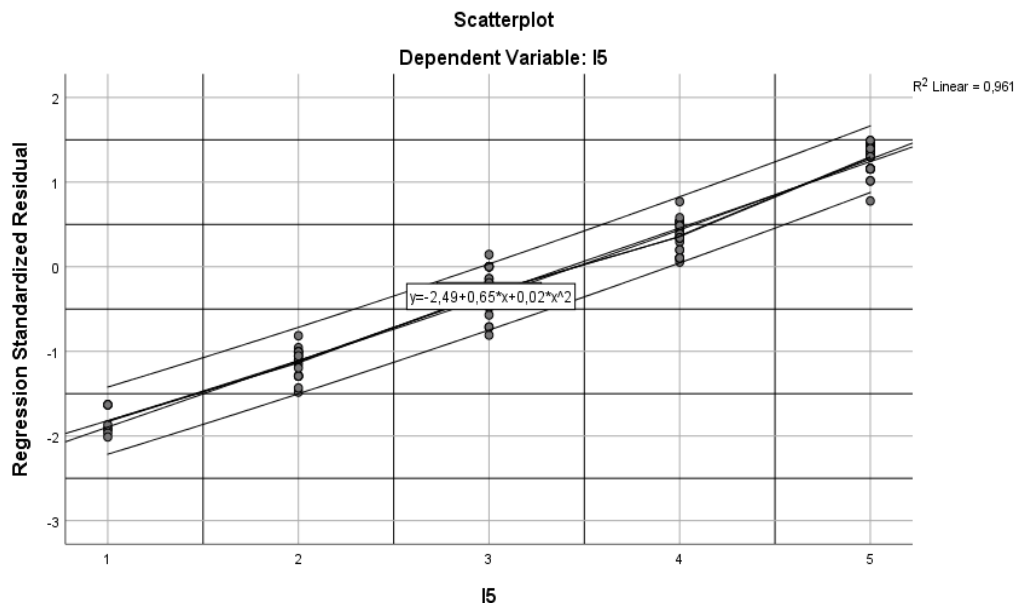


Figure 10b. RSR V5*academic grade (Likert)

Conclusion

The new scale offers several advantages over the traditional Likert scale. It incorporates a binary choice, which is particularly useful for predictive modeling, along with a relative interval scale featuring 10+10 intervals. In social sciences, especially in attitude research, it is not expected that absolute distinctions can be made when assessing the strength of agreement or disagreement. However, respondents are expected to recognize differences across 10 distinct intervals (NEGATT-POSATT; min-max).

The tolerance for distinction error is ± 1 scale interval, i.e., 5% between intervals on a 10+10 scale. Since the respondent evaluates only one dimension at a given time (agreement or disagreement), but we use a total scale of 20 intervals, it is reasonable to expect some error in the precision of distinguishing adjacent intervals.

The scale consists of 10 degrees of agreement (POSATT) and 10 degrees of disagreement (NEGATT). After coding, the scale features 20 rank intervals or degrees (1, 1.1, 1.2, ..., up to 3). This design allows for high resolution in measurement. Respondents are expected to distinguish between more

distant points (for example, 8 vs. 10) more accurately than between neighboring intervals (such as 8 vs. 9). Due to the limited ability to differentiate within the 10 degrees, we assume an error of ± 1 degree on this scale. When considering the entire 20-degree scale, this error is proportionately adjusted to 5% (1 out of 20). If a respondent estimates the intensity of negative attitudes between 8 and 10, this is likely a more precise estimate. However, if the choice is between 8 and 9, the potential for error increases because neighboring values are harder to distinguish. This error can impact the fine-tuning of statistical analyses, such as in reliability calculations or factor analysis. Therefore, the precision is 95%, or there is a 5% probability that subjects will misjudge the intensity due to difficulty distinguishing between adjacent intervals (Figure 11).

This paper highlights various benefits of the new scale compared to the Likert scale, both in descriptive and inferential statistics. The new scale significantly enhances statistical analysis capabilities by separating the data set into positive (POSATT) and negative (NEGATT) attitudes. This allows for differential analyses of positive and negative attitudes and improves prediction modeling. Such capabilities are particularly valuable in economic research, as they enable separate analyses and comparisons of positive and negative preferences (NEGATT and POSATT). The dual measurement offered by the scale, including binary outcomes (agree/disagree; yes/no) along with additional relative interval measurements, expands the range of statistical analyses available. This can lead to more accurate, objective, and reliable conclusions.

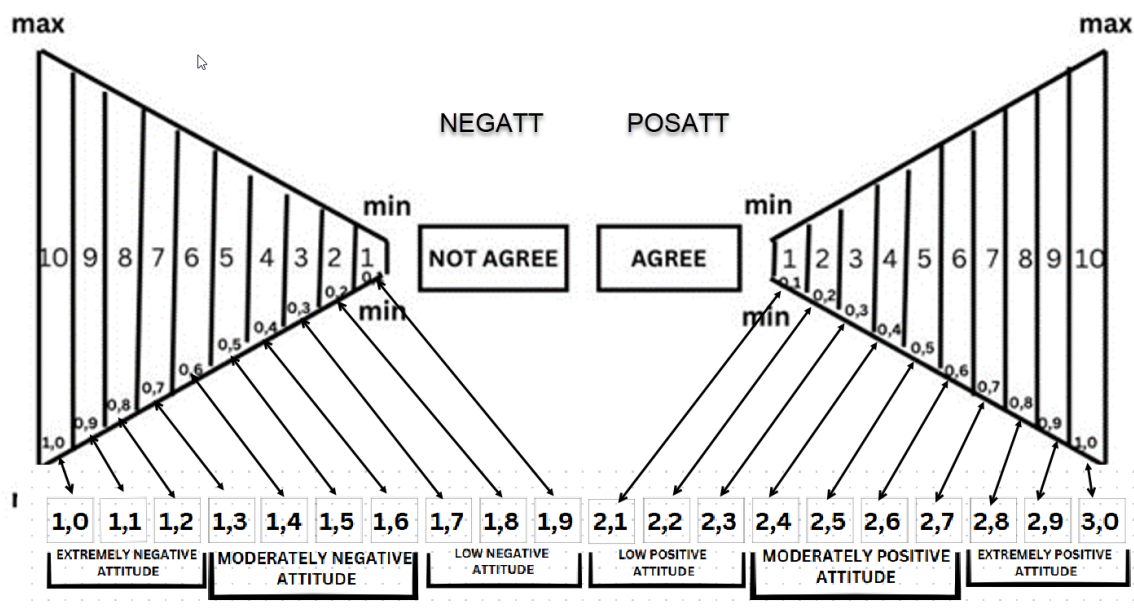


Figure 11. New scale with coding

It is recommended to use the scale for categories with large sample sizes. Further research on the new scale is anticipated, taking into account its distinct advantages as well as certain limitations.

Limitations of the new scale

The Likert scale has been the subject of criticism in many scientific journals for decades. Despite this, it remains dominant in a number of scientific disciplines. The new scale is statistically more justified, more precise, and more accurate, although there is a need for further research on its advantages and disadvantages.

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Conflict of Interest

Author have no conflict.

Statement of Disclaimer

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Generative AI Statement

During the preparation of this article, we used ChatGPT for translation from Croatian to English language and for additional grammar and clarity improvement. The author reviewed and edited all content as needed and takes full responsibility for the published version.

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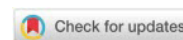
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Enhancing Human-Machine Cooperation through the Integration of Empathetic AI into Corporate Cybersecurity and Forensic Operations

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Abstract: In order to strengthen the cooperation between humans and machines, empathetic artificial intelligence is increasingly emerging as a key player. This cooperation is particularly evident in corporate cybersecurity and digital forensics. Today, thanks to the inclusion of emotional awareness in artificial intelligence systems, many organizations can more easily monitor the cognitive load of their analysts during critical security situations. Empathetic artificial intelligence in corporate cybersecurity is a new force for proactive threat detection, compliance and risk management. It helps analysts to respond to constant cyber threats more effectively, and in forensic investigations it offers great support in emotional and behavioral analysis. In this way, in cybercrime investigations, through the observation of anomalies and their patterns, decisions are made with a higher degree of accuracy. However, this technology still faces numerous challenges, such as accurately reading emotional cues, protecting sensitive data, and ensuring ethical management. In any case, well-defined frameworks that promote cooperation between artificial intelligence and humans are the necessity of the present, in order to remove these barriers. It is undeniable that empathetic artificial intelligence has the potential to create security ecosystems that are more adequate, reliable and above all focused on human needs. Therefore, in the near future, it will revolutionize the field of corporate cybersecurity operations and digital forensics, but only if it is smartly implemented.

Keywords: *empathetic artificial intelligence, human-machine collaboration, corporate cybersecurity, forensic operations, cybercrime investigation,*

Introduction

As Cuff et al. (2014) argue, empathy, or sharing feelings with social others, is essential for both strong relationships and mental well-being. Brink et al. (2011) define empathy as simply putting oneself in the shoes of another person by understanding the situations and realities they face. It can foster participation because it allows a person to put aside their current situation and be open to others (Ashworth and Lucas, 2000). Building engagement and trust between humans and computers increasingly depends on the ability to personalize interactions based on the unique characteristics of the user (Baltezarević and Baltezarević, 2024).

AI is transforming how we go about our day-to-day lives, influencing everything from simple tasks to more involved decision-making scenarios. One of the most intriguing breakthroughs in this field is the creation of empathetic algorithms. By merging emotional intelligence (EI) with cognitive computing, these algorithms elevate the interaction between humans and machines. This development not only marks a pivotal moment in AI's evolution but also unlocks new avenues for its use in fields like healthcare, education, and customer service, where grasping and responding to human emotions can lead to much better results (Kukreja et al., 2022).

Lately, the role of Artificial Intelligence (AI) in cybersecurity has evolved significantly. It's no longer just about technical detection and response; we're now looking at the human elements involved as well. Enter empathetic AI, this innovative technology can understand and react to human emotions and thought processes.

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It's becoming a game-changer for security analysts, particularly when they're under pressure. By alleviating cognitive overload, it helps improve their decision-making skills.

Empathetic algorithms are crafted to tackle the intricate and often nuanced realm of human feelings, unlike standard algorithms that focus solely on objective data. They do this by merging natural language processing (NLP), facial expression analysis, voice tone recognition, and other sensory inputs to identify emotional states (Zhou et al., 2019).

They contribute to fostering more honest interactions by modifying their responses according to the situation and human feelings (Baltezarević and Baltezarević, 2025). In many areas, but especially in risky ones, this collaboration between humans and AI has proven to be very reliable and is considered more effective than completely replacing humans with artificial intelligence (Bansal et al., 2021).

However, developing human-centred AI models to support people and creating human-facing interfaces for people to interact with the AI provide additional challenges for the partnership. For example, when it comes to AI-assisted writing, we need to develop AI models that produce practical writing recommendations while also creating human-facing systems that enable users to view, comprehend, and act upon those recommendations at the appropriate moment (Hirsch et al., 2017).

However, even highly skilled demonstrations of empathy have the potential to alienate recipients, and there is always the possibility of empathic error. Instead, a human-first approach is needed (Main et al., 2017), as has been done in the field of medicine to understand the effects of physician empathy on patients (Cadiente et al., 2023). A productive partnership in which AI merely assists, rather than controls, the creative process can be sustained by establishing explicit rules and responsibilities (Jylkäs et al., 2025).

AI has the potential to produce complex malware that can automate time-consuming phishing attempts, adjust to security precautions, and even carry out deepfake attacks that alter audio and visual data (Hussain et al., 2021). The increased availability of AI technologies and techniques is lowering the barrier to entry for hackers, leading to more complex and targeted cyberattacks. A proactive cybersecurity strategy is necessary, as defensive tactics are constantly changing in the AI realm (Rafy, 2024). Emotional intelligence in artificial intelligence can significantly improve human-computer collaboration in identifying cyber threats and ultimately, preventing them (Martin, 2022). For this reason, the main goal of incorporating artificial intelligence into cybersecurity is to improve the skills of analysts so that they are better able to deal with increasingly complex cyber threats, which have been noticeably increasing recently (Baruwal Chhetri et al., 2024).

Research indicates that AI systems can provide substantial support to digital forensic analysts, assisting them in tasks such as organizing evidence, identifying anomalies, and tracing the origins of threats, all by integrating machine learning with human intuition (Akeiber, 2025). What's more, AI can handle huge amounts of forensic data much more effectively than traditional methods, while human analysts bring in the necessary context and legal insights (Dunsin et al., 2024).

This article examines the concept of empathetic artificial intelligence and looks at how it can improve collaboration between humans and this new technology. There is a particular focus on areas such as corporate cybersecurity and forensic investigations, and how empathetic AI can improve their processes. We're about to explore the real-world applications of empathetic AI, focusing on the benefits it offers and the ethical and practical challenges we might encounter along the way. To steer our discussion, we'll concentrate on three main research questions. First, we'll examine how empathic AI systems are being utilized in fields like corporate cybersecurity, forensic operations, and human-machine interactions (RQ1). Next, we'll look into the possible benefits of integrating empathetic AI into these areas. This approach could strengthen trust, improve decision-making, and promote collaboration during challenging investigations and operations (RQ2). Finally, we'll identify the key technical, ethical, and operational hurdles associated with implementing empathetic AI in corporate cybersecurity and forensic investigations, while also brainstorming solutions to tackle these challenges without sacrificing that crucial human oversight (RQ3). This review brings together insights from psychology, human-computer interaction, artificial intelligence, and cybersecurity to create a more holistic framework for developing empathetic AI in human-machine collaboration. We'll also point out existing research gaps and propose future research directions to improve corporate cybersecurity practices, forensic processes, and the design of AI-assisted investigations.

Foundations of Empathetic AI and Human–Machine Collaboration in Corporate

Cybersecurity and Forensic Operations

These days, we encounter AI in our daily lives more than we realize. Whether it's snapping photos on our smartphones, streaming our favorite tunes, or scrolling through social media, AI is often working behind the scenes. This can lead to a big gap between how often people think they interact with AI and how often actual AI experts believe they do (Richter, 2025). This difference highlights how crucial it is to create AI systems that are not only transparent but also easy for users to understand.

One human trait that greatly enhances our ability to communicate and make decisions is emotional intelligence. It encompasses the ability to recognize, understand, manage, and skillfully use emotions (Ghotbi, 2023). Since it first hit the scene, ChatGPT, an AI chatbot built on a powerful language model (LLM), has left both researchers and everyday users in awe with its knack for mimicking human-like traits. One standout trait is empathy, which involves understanding how others feel, viewing situations from their perspective, and genuinely caring about their emotions (Decety and Cowell, 2014). Thanks to this ability, modern AI systems can convey social and emotional signals, which can lead to real-world effects. For example, when AI shows more empathy, it can lead to better user compliance and acceptance of AI services (Adam et al., 2021). Depending on how AI shows empathy, it can also determine the quality of interactions (Vossen et al., 2015).

In the world of corporate cybersecurity, empathetic AI can really help connect the dots between technical alerts and how humans interpret them. Take, for instance SOC that's swamped with a flood of low-level alerts. An AI system that keeps an eye on the cognitive load of analysts can adapt its support on the fly: it might downplay less urgent alerts, offer concise insights, or even recommend collaborative triage when it senses that the team is feeling overwhelmed (as seen in adaptive decision-support frameworks) (Albanese et al., 2025).

It's essential to make a clear distinction between affective empathy, which involves sharing or mirroring someone else's emotional state, and cognitive empathy, where we understand another person's perspective or mental state. While AI systems are primarily concerned with cognitive empathy, humans generally employ both forms (Hou et al., 2024). This contrast highlights the existing philosophical and technical limitations of empathetic AI.

AI is now capable of demonstrating cognitive empathy and generating responses that often come across as empathetic. It's been proven to recognize human emotions (Ong et al., 2019), show facial expressions (Mishra et al., 2023), and effectively promote empathetic interactions (Sharma et al., 2023), thanks to significant advancements in how we approach emotional inference. However, Perry (2023) points out that while AI can mimic empathy, it lacks the ability to convey true concern or to indicate that the person it's interacting with holds any real significance.

When it comes to forensic operations, empathetic AI is truly a game-changer, delivering benefits that reach far beyond mere data analysis. By analyzing behavioral cues, tone, and communication patterns, it can help investigators pinpoint potentially malicious insider actions or social engineering efforts. Rather than just relying on transaction logs, this AI can interpret emotional or hesitant speech and connect it to known threat models. This evolution allows AI to act as a partner in investigations, enriching the collaboration between humans and machines and leading to more insightful and effective outcomes.

More and more people are choosing conversational AI over phone calls, which is one of the key reasons behind the rise of AI-powered customer service. A survey conducted in 2024 found that 82 percent of consumers preferred chatting with a bot rather than waiting for a customer support representative to pick up. Even more striking, 96 percent of respondents felt that businesses should really consider using chatbots instead of relying on traditional customer service (Coppola, 2024). The majority of domain-specific chatbots used for such interpersonal service settings rely solely on text-based communication via a webpage or mobile application that people access via their personal devices (e.g., phone, tablet, laptop, etc.), although some generic conversational AI agents, like Alexa and Siri, use spoken and audio-based interactions (Pamungkas, 2019).

Natural language processing (NLP) is a field of AI that focuses on how computers and humans communicate (using spoken or written natural language). It bridges the gap between humans and computers, allowing computers to understand and interpret human language (Jurafsky and Martin, 2024).

NLP allows designers to carefully assess individual (or micro-level) experiences and expectations by analyzing consumer input (Jylkäs et al., 2025).

In the real world, blending NLP with empathetic AI systems involves juggling various inputs like text, voice tone, and even facial expressions. The whole process revolves around understanding emotions, which shapes how responses are formulated. It begins with spotting an emotional state, assessing its valence and intensity, and then picking or crafting a response that matches a particular empathy strategy (Akhtar et al., 2025). Research has shown that third parties evaluate manifestations of empathy elicited with assistance more favorably than human emotions (Ayers et al., 2023). Additionally, through the analysis of mood and user research data, NLP enables designers to assess consumer feedback to understand their moods, preferences, and desires at the meso level of the service ecosystem (Liu, 2012). NLP helps develop successful content strategies (by assessing user language patterns and interactions) by ensuring that communication is user-centered and that the different components of the service coherently respond to user requests (Liddy, 2001).

Successful collaboration requires understanding the dynamics of interaction between AI and humans. Studies have shown that decision-making and user trust can be largely disproportionate to the apparent definitiveness of AI responses (Zhang et al., 2020). To improve collaborative outcomes, AI systems must be designed to be trustworthy (Steyvers et al., 2025). Nevertheless, it can be concluded that one should neither rely too little nor too much on the individuality of AI decision-making. A balanced relationship of human-machine collaboration will yield the best outcomes.

The learning apprentice model, which is also known as the human-in-the-loop (HITL) approach, treats AI as a supportive teammate for human workers. This idea posits that AI learns by watching how humans make decisions and then uses those insights as additional training data. This not only allows AI to provide assistance (in real time), but also helps it learn from a diverse range of human input. In this way, it potentially allows it to surpass the knowledge of individual team members. With that in mind, the effectiveness of this learning process largely depends on the expertise of the human team and the availability of pertinent information (Esteve et al., 2017). This collaboration between AI and humans enables AI to harness human creativity and empathy, which enhances its capacity to identify emotional cues and is essential for creating more compassionate user experiences (Jylkäs et al., 2025).

Furthermore, the latest developments in multimodal emotion recognition, blending speech, facial expressions, and text, can really enhance an empathetic AI's skill in recognizing analysts' emotional states on the fly (Alnuaim et al., 2022). By utilizing this multimodal approach, AI systems in SOC's or forensic teams can more effectively adjust their communication and support based on the human operator's emotional and cognitive load, which helps build collaboration and trust.

Researchers took a closer look at a collaborative design that tweaks existing human responses to make them more empathetic. This is different from the AI-only approach, which involves generating empathetic dialogue from scratch (Lin et al., 2019). By adding new empathic phrases or replacing existing low-empathy sentences with more caring alternatives, this design can significantly improve its empathetic responses (Sharma et al., 2021). Furthermore, once AI is trained to recognize emotions, it can be used to create programs that react in a helpful and appropriate manner. For example, an AI chatbot designed for customer support could be trained to detect and address customer frustration. To enhance customer satisfaction and improve the overall experience, the chatbot might provide additional support, apologize for any inconvenience, or connect the customer with a live representative when they become upset. The public's acceptance of AI in various sectors largely depends on the trust customers place in it, which is fostered by these seemingly empathetic AI solutions (Clark, 2023).

This highlights the importance of integrating automated systems with human components (Papakonstantinidis et al., 2021). A recent example showed how human-AI collaboration led to more empathetic peer-to-peer mental health support conversations, as opposed to responses from humans alone (Sharma et al., 2023). Enabling machines to understand and respond to human emotional states improves the efficiency, naturalness, and ultimately humanness of interactions. This integration has the potential to completely transform human-robot interactions, making them more natural and aligned with human needs and expectations (Kukreja et al., 2022).

A better understanding of how AI can interpret human experiences could be of great help in the ethical development of this new technology. A good example would be the fact that AI is increasingly being used in the care of the elderly, to prevent their cognitive decline and at the same time improve their

quality of life. This is achieved through diverse social interactions and individualized cognitive training (Balcombe, 2023). By integrating technological, theoretical, and psychological perspectives, these interdisciplinary methods highlight the complex nature of self-awareness in artificial intelligence.

Melloni et al. (2014) aimed to develop personal assistants that could understand and predict human emotions and social interactions. Their study used deep learning (DL) algorithms to identify social cues and emotional states. The researchers used (unstructured) data from social media, videos, and text messages for their study. The results ultimately showed that AI assistants can correctly recognize social interactions and emotional states. AI systems, however, need to build a good relationship with their human partners to reach their full potential. This will enable harmonious partnerships based on a shared understanding of thoughts or feelings. Sensitivity and humor, which increase likeability and promote co-operation by 30% (Short et al., 2010), could improve this relationship (Niculescu et al., 2013).

The combination of empathetic AI and human interaction is a crucial advancement in enhancing user experiences and creating technology that benefits society. By using thoughtfully crafted algorithms that can grasp and react to human emotions, alongside human insight and ethical considerations, we can create AI systems that not only assist with daily tasks but also encourage responsible and socially aware practices. This collaboration between people and empathetic AI opens up a future where technology aligns with our values and needs.

Exploring Applications and Challenges of Empathetic AI in Cybersecurity

Protecting systems, networks, and data from online threats while maintaining availability, confidentiality, and integrity in the digital sphere is known as cybersecurity. It includes a variety of tools, tactics, and procedures to reduce risks and protect important assets (Olagunju et al., 2024). Critical infrastructures like water supplies, petrochemical facilities, nuclear power plants, and transportation infrastructure systems have all been the subject of cyberattacks in recent years, which have compromised sensitive data and caused power outages (Plêta et al., 2020).

AI-driven technologies, however, have both advantages and disadvantages when combined with cyber security. A portion of AI supports cyber resilience, while another component trusses penetration. Although there is a wide range of research on AI-based applications, security concerns are significantly more important than preventative measures (Tyugu, 2011). Machine learning (ML) models empower machines to make predictions or judgments based on a mathematical representation of carefully chosen data, all without needing explicit programming. To kick off AI in cybersecurity, the initial step is to pre-process the data before it's input into the ML models. This method reveals insights into the data by assessing feature importance or ranking the key elements, and it's usually quite clear. Grasping how models make decisions is crucial for these strategies, as it helps ensure that we can make the right calls to spot any unusual behavior. After the data has been processed and trained, feature engineering helps identify anomalies or outliers in the dangerous patterns (Wang et al., 2016).

In the world of corporate cybersecurity, empathetic AI can be a game-changer for analysts. It goes beyond just spotting technical glitches; it also offers insights into potentially risky behaviors that take human emotions into account. For instance, when the number of alerts spikes, an AI system that recognizes cognitive load and emotional stress can help prioritize warnings in a way that eases the burden and enhances decision-making. This approach strikes a balance between automated detection and human intuition, which is crucial in high-stakes security situations (Mohsin et al., 2025).

To keep an eye on network traffic, we use intrusion detection systems (IDS) that are designed to flag any suspicious behavior or policy violations. Conventional IDS typically rely on rule-based methods and static signatures, which can be limited in their ability to catch new or evolving threats. The game has changed with the advent of artificial intelligence, particularly machine learning and deep learning, which empower these systems to identify unusual patterns and adjust to new attack vectors. Conventional intrusion detection systems (IDS) mainly rely on static signatures and rule-based approaches. IDS cannot always detect new threats and its ability may be limited, but with the advent of AI, positive changes have occurred and these new systems can now recognize all unusual patterns and adapt to them in the right way (Ajibola et al., 2025). Threat intelligence and prediction, to identify possible cybersecurity risks and predict possible future attacks, involve the collection, processing, and interpretation of data. By automating threat

detection and pattern identification, AI has significantly advanced this field. For example, AI models using natural language processing (NLP) can analyze text data from social media to extract useful information to improve cyber-security preparedness (Zangana et al., 2025). In the realm of forensic investigations, empathetic AI offers a richer analysis of attacker techniques and insider threats. It doesn't just look at logs or transaction patterns; it also interprets the emotional and behavioral context surrounding communications or suspicious activities. By integrating human involvement into the process, the system can recommend lines of inquiry that balance analytical precision with the human context of incidents, ultimately boosting both technical effectiveness and the sensitivity of investigations (Schaberreiter et al., 2024).

Today's security management systems often allow for the recording of suspicious behavior or data flow from hackers, moving from active defense techniques to more proactive approaches. The technique of enticing the adversaries is commonly known as "honey pot", and it helps system analysts obtain crucial data on the attack signatures and strategies of attackers. Honeypot's analysis can also be used to mimic intrusion detection systems (IDS) or even deflect attacks from important targets (Devi Priya and Chakkaravarthy, 2023). A huge amount of sensitive (real-time threat intelligence) data can be found in the data used by the Honey Pot process. Security analysts and forensics can identify new attack patterns by examining this data (Li et al., 2022).

Whenever AI processes sensitive data for security reasons, privacy concerns arise. Over time, as AI technologies become more sophisticated, as they can draw complex conclusions from aggregated data, these concerns have escalated (Hitaj et al., 2017). However, these technologies are constantly improving, and progress fosters trust and reliability on the digital platform (Anica Popa et al., 2021). But safeguards for the use of this private information aren't always the best ones. The integrity of the person who believes that AI-based technological platforms are reliable may not always be protected by these procedures (Gupta et al., 2023).

AI can provide significant assistance by identifying and warning about malicious software (malware), or providing support in conducting cybersecurity training and vulnerability assessment (Karuna-murthy et al., 2023). The use of large language models (LLM) for intrusion detection or phishing emails has recently gained significant popularity (Kheddar, 2024). Convolutional neural networks (CNNs) can extract complex information from high-resolution photographs and contribute to facial recognition with high accuracy (Ali et al., 2021). Similarly, ML-based behavioral biometrics tracks user behavior, which may include keyboard typing speed, mouse movement dynamics, or analyzing touchscreen gestures, to identify patterns or anomalies that could be signs of fraud (Bansal and Ouda, 2024).

AI cues can easily deceive people into believing they're interacting with sentient beings, which often leads to the use of learned behaviors and scripts. A recent incident involving a finance employee at a multinational company in Hong Kong, who was tricked into transferring a staggering \$25 million to scammers, really highlights this problem. During a video call, the scammers posed as the company's chief financial officer, using deepfake technology (Murphy, 2024). This scenario really underscores our natural tendency to trust rather than question, since being skeptical often takes more mental effort (Gilbert, 1991). In simpler terms, if AI can trigger certain responses in people, they might interact with technology just like they do with each other, tapping into those learned social behaviors. To make the most of technology, it's crucial to grasp these cues so we can develop frameworks that encourage its adoption (Kolomaznik et al., 2024).

The potential of empathetic AI in cybersecurity really shines when we look beyond just the technical side and think about how human operators and users emotionally connect with these systems. Empathetic AI agents can keep an eye on an analyst's stress levels during an incident, pick up on any confusion or hesitation in their decision-making, and offer helpful prompts or different perspectives. An AI agent can identify when a security engineer is stuck (for example, in incident assessment) and offer a simpler and more efficient explanation (in order to reduce cognitive fatigue), or suggest that the engineer contact a colleague who can help them make the right decision (Bhatia et al., 2024).

Introducing empathetic AI into cybersecurity practices certainly presents a few unique challenges. One of the main concerns is making sure that emotional cues are understood correctly. We definitely want to avoid any misunderstandings, whether they're false positives or negatives. It is vital to maintain human autonomy, so that AI does not steer our decisions in unwanted directions. In addition, emotional data must be treated with the same seriousness as, for example, transactional or behavioral data. However, there is a possibility that malicious actors can provide misleading emotional signals, which can compromise the monitoring of the system. The way AI is used in advanced social engineering tactics (such as "FraudGPT"

and “WormGPT”) highlights how fraudsters can exploit technology that mimics human empathy to break trust and bypass defense systems (Falade, 2023).

Humans and machines must have clear roles, and governance frameworks should specify when empathetic AI can intervene and when it is necessary for humans to take full control. It must also be ensured that data on emotional reactions is stored and protected from any misuse. Research in this area points to the idea that collaboration between humans and AI, where empathetic AI provides assistance rather than taking control, could be a fantastic model for cybersecurity operations (Sarker et al., 2023). As the demand for explainable AI (XAI) rises in security contexts, it's becoming increasingly clear that empathetic AI systems need to be upfront about their emotional insights, not just their threat detection abilities (Srivastava et al., 2022). Findings show that people who interacted with an empathic AI were 20% more likely to follow its recommendations, highlighting a significant increase in feelings of support and confidence (Liu and Sundar, 2018). Additionally, Portela and Granell-Canut (2017) looked into how AI's empathetic responses impacted user interactions. Their findings showed that 68% of users felt more emotionally engaged when the AI displayed empathy, compared to those who interacted with non-empathetic AI.

Finally, it is important to note that while the technical elements of AI-driven detection, prediction, and response are undoubtedly vital, the next challenge is to figure out how these systems can better connect with human users for even greater operational effectiveness. AI when designed with empathy in mind in cyber-security can truly be a game-changer. This approach allows teams to remain resilient when the pressure is on. In order to fully exploit this enormous potential, we must confront a complex web of obstacles along the way. A recommendation for future research is that it should focus on how empathetic signals in AI monitoring affect the quality of decision-making in SOC's. Also, to create metrics to measure the effectiveness of emotional AI and to develop standardized frameworks in security operations for managing emotional data.

Discussions

Cooperation between people and machines will be significantly improved in the coming period through the use of empathic artificial intelligence and will become a higher priority in organisations, and this will be particularly reflected in cyber security. This advanced type of artificial intelligence is designed with the primary goal of understanding human emotions and reacting accordingly. These empathic systems can contribute to reducing the mental effort of employees at times when they are not making the most adequate decisions, which can be problematic when dealing with environments that function under high pressure, such as those in security operations centres (SOC) (Mohsin et al., 2025). In any case, by prioritising during crises that carry security risks, empathic artificial intelligence can help analysts perform their work tasks more efficiently (Liu and Sundar, 2018).

However, despite the obvious advantages, there are still significant difficulties in this area that will be overcome over time. For example, the incorrect interpretation of emotional cues represents a significant obstacle, because their misinterpretation can produce incorrect suggestions that, in addition to undermining trust, negatively affect efficiency (Hitaj et al., 2017). Furthermore, in practice there are many cases of malicious people who could misuse empathic artificial intelligence and offer untrue emotional cues. In that way, they would bypass security measures and influence distorted decision-making (Falade, 2023). In the scientific literature, most research on empathic artificial intelligence in cybersecurity is currently theoretical or based only on simulations, a fact that points to the need for further research to address the practical consequences, reliability and moral implications of these systems (Sarker et al., 2023).

In order to introduce empathetic artificial intelligence, in addition to the moral and technical aspects, it is essential to establish a culture of cyber security, which will recognise the value of emotional intelligence and be ready to accept the insights of artificial intelligence. Training employees to better understand feedback received through artificial intelligence is key, but care must be taken that over-reliance on it or misinterpretation of emotional cues can have the opposite effect. It is also crucial that the human element remains a priority in collaboration with artificial intelligence (Kolomaznik et al., 2024). Of course, during analyst training, top priority must be given to emotional literacy in order to encourage fruitful collaboration with these systems (Liu and Sundar, 2018). The synergy of emotional intelligence with instant detection of cyber threats is a new strategy, which aims to overcome fatigue and provide suggestions to

analysts. This combination of humans and technology represents a strategic advantage (Bhatia et al., 2024), as it improves efficiency, contributes to better and smarter task allocation, and, equally importantly, shortens incident response times in SOC's (Liu and Sundar, 2018).

Studies investigating this kind of collaboration between humans and artificial intelligence in SOC's have revealed a worrying trend. It has been observed (although not recommended) that analysts are increasingly relying on artificial intelligence systems to make decisions, which can cause a risk of overburdening and the reduction and dulling of skills. Therefore, empathetic artificial intelligence helps human analysts, but only as long as it is used in the right way and does not affect their individual situational awareness and does not undermine their decision-making skills (Yaich et al., 2024). All of this indicates that it will take time for human analysts and parallel developing artificial intelligence systems to adapt to each other. Recent research has shown that humans working with artificial intelligence can significantly improve their ability to identify delicate cyber threats (Cohen et al., 2025). Adapting your answers to the way human analysts think builds trust and ensures consistency in understanding while performance remains high.

Conclusions

In cybersecurity, empathetic artificial intelligence is poised to improve decision-making, build and nurture trust, and increase the resilience of human analysts. These systems reduce cognitive effort and through human collaboration improve outcomes in high-stress cyber security scenarios by engaging emotional awareness (Kolomaznik et al., 2024). By reducing fatigue and prioritizing, allowing analysts to concentrate on the most pressing security issues, empathetic artificial intelligence can significantly increase workplace efficiency (Liu and Sundar, 2018). However, we must overcome a number of organizational, ethical and technical challenges, including avoiding aggressive exploitation, to fully exploit these benefits.

To fully understand how empathetic AI impacts decision-making, future research should focus on its use in security operations centers (SOC's). Also, collaboration on a common goal between experts from many fields is necessary for the development of this technology to be appropriate (such as AI and cybersecurity experts, but also psychologists and human-computer interface experts). This is the only right path to a balanced development of empathetic AI that will not only improve security, but will also be in line with both human values and operational needs. In any case, the potential of this technology to significantly advance the field of cybersecurity is undeniable, primarily by building better interactions between humans and AI through careful consideration of its design and management.

Modern organizations facing real and potential cybersecurity challenges should definitely consider using agent-based or empathetic artificial intelligence systems in the coming period. These systems must be flexible enough to adapt fully to the analyst's mental states as well as the number of alerts. This field (human-technology collaboration at an empathetic level) is still in its early stages of development and further scientific studies are needed to better understand the long-term impacts of these systems on human competence, self-confidence, short-term productivity gains and, perhaps most importantly, cognitive resilience.

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Author Contributions

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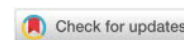
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Criminal Treatment of The Misuse of Artificial Intelligence in The Creation of Pornographic Content and the Psychological Consequences on the Victim

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Abstract: The abuse of artificial intelligence in the creation of pornographic content represents a modern form of socially dangerous behavior that requires an adequate criminal law response and an interdisciplinary approach. The development of generative technologies has enabled the creation of highly realistically manipulated or completely synthetic content, which opens up new types of violation of the right to privacy, dignity and personal safety. These forms of abuse include the use of “deepfake” technology, the digital manipulation of existing visual materials, as well as the generation of content that imitates real people without their knowledge or consent, thereby further complicating the determination of responsibility and the protection of victims. The current criminal legal framework is based on the protection of sexual freedom, honor and reputation, as well as the protection of minors, whereby the question of its normative completeness and effectiveness in the context of accelerated technological development and new forms of digital violence is raised. In addition to the legal aspect, this phenomenon is also characterized by pronounced psychological and victimological effects, which are reflected in the impairment of mental health, the feeling of stigmatization, the loss of a sense of security and the long-term consequences for the social functioning of the victims. The work is methodologically based on a theoretical analysis of relevant positions in domestic and foreign literature, a normative analysis of valid legal regulations, as well as on empirical research conducted among students using the survey method. Descriptive analysis was used in the processing and interpretation of collected data, with the application of inductive and deductive methods in order to draw conclusions. Special attention was paid to examining respondents' views on the social danger of this phenomenon, their level of information, as well as the perception of the need to improve criminal law regulations. The aim of the work is to point out the shortcomings of the existing criminal legal framework, as well as the need for its normative improvement and the development of more effective preventive and protective mechanisms.

Keywords: artificial intelligence, deepfakes, pornographic content, criminal protection, psychological consequences, prevention.

Introduction

The development of artificial intelligence in the last decade has brought significant innovations and improvements in numerous areas of social life, from medicine and education to security and industry. However, in parallel with the positive effects, this technology also opened up space for new, sophisticated forms of abuse that represent a serious challenge for modern legal systems and “at the same time opens up new questions and dilemmas for the scientific and professional public” (Čučilović, 2024, p. 325). One of the particularly worrying phenomena is the use of artificial intelligence in the creation of pornographic content, especially in situations where such content is produced and distributed without the knowledge or consent of the persons depicted in it. It should be said that pornographic content has been present and available to users since the very beginnings of expansive technological development (Stardust et al., 2023; Mink, Qin and Redmiles, 2026). What has drawn additional attention to this problem is the use, that is, the abuse of the capacity of artificial intelligence in this area. This phenomenon imposes the need for

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an interdisciplinary approach that includes criminal law analysis, as well as victimological and psychological aspects of victim protection.

Abuse of artificial intelligence in this context can be defined as the use of algorithms and machine learning models to generate, manipulate or distribute pornographic material in a way that violates basic human rights, dignity and privacy of individuals. The most prevalent forms of this abuse include the so-called „deep-fake” technology, with the help of artificial intelligence, the face of one person realistically fits into the body of another in explicit video or photo content, then the creation of completely synthetic characters that can be based on real people or their characteristics, as well as the modification of existing photos and recordings in order to sexualize them. In addition, a special problem is the cases of the so-called revenge pornography, where content generated in this way is used as a means of blackmail, intimidation or public humiliation of the victim, as well as situations involving minors, which further increases the social danger of these actions.

The specificity of the mentioned forms of abuse is reflected in their easy availability, relatively low technical barriers to execution, as well as the speed and scope of their spread through digital platforms. At the same time, the anonymity of the perpetrators and the transnational nature of the Internet make it difficult to identify and prosecute the perpetrators, which represents an additional challenge for the criminal justice system. More precisely, the very possibility that any form of computer crime is committed in one country, and that the consequences arise in another country or in several other countries, along with the mentioned anonymity of the perpetrator, clearly indicates significant difficulties in discovering, proving and prosecuting the perpetrators (Pisarić, 2013, p. 292; Baron Quintero, 2023, p. 176; Čučilović, 2026, p. 64; Matijašević, 2013, pp. 18-19). In fact, cyberspace as well as virtual reality enables completely new patterns of action, the basic characteristic of which is global and transnational in scope, which exceeds the territorial control of national states (Matijašević Obradović and Zarubica, 2019; Hajela, Chawla and Rasool, 2021; Subotin and Matijašević Obradović, 2019). The consequences for victims often go beyond the legal sphere, including serious psychological trauma, feelings of shame, anxiety, depression, as well as disruption of social and professional relationships (Veljković, Čurčić and Gavrilović, 2024, p. 1451).

This phenomenon, however, goes beyond the scope of individual injuries and points to wider social implications of the abuse of modern technologies. Its reliance on manipulation and the generation of believable but inauthentic representations raises the question of the boundaries between real and artificially constructed content in the digital space. In this sense, the mass availability and use of such technologies contribute to the destruction of trust in the credibility of digital media, deepening the problem of disinformation and making it difficult to reliably distinguish authentic from generated content (Ranjan, 2023, p. 116).

In modern literature and practice the term “deep nude” is increasingly used to denote a special form of digitally generated pornographic content created by the application of artificial intelligence. This term includes exactly visual representations in which, with the help of appropriate algorithms, clothes are removed from existing photos or videos, the generation of a naked human body, as well as the creation of a believable illusion of nudity. In addition, it is possible to construct completely new digital representations of naked figures that are visually difficult to distinguish from real persons (Kopecký and Voráč, 2026, p. 545).

Bearing in mind the growing prevalence and complexity of abuse of artificial intelligence in the creation of pornographic content, as well as its pronounced social and psychological consequences, there is a need for a deeper understanding of the perception of this phenomenon in modern society. In this context, conducting empirical research among the student population is of particular importance, since it is a group that is highly exposed to the digital environment and modern technologies. Examining their views on the social danger of this phenomenon, the level of information, as well as the need to improve the criminal law regulation, enables an overview of real social needs and contributes to the formation of a more adequate normative and institutional response to this modern challenge.

The criminal legal framework and the challenges of the legal qualification of the abuse of artificial intelligence in the creation of digitally generated pornographic content

The development of artificial intelligence opens numerous issues related to the protection of human rights and points to the importance of improving criminal law protection in order to adequately respond to new forms of abuse in the digital environment (Matijašević, Bećirović, Nikšić and Mašović Muratović, 2026, p. 38).

The Criminal Code of the Republic of Serbia prescribes the criminal offenses of unauthorized pho-

tography (Article 144) and unauthorized publication and display of other people's writings, portraits and videos (Article 145), which, to a certain extent, can be linked to the creation and distribution of fake digital pornographic content.

The crime of unauthorized photography from Article 144 of the Criminal Code protects an individual's right to privacy, criminalizing the act of unauthorized photography, film, video or other recording of a specific person, provided that it significantly intrudes into his personal life. An essential element of the existence of the act is precisely the existence of a qualified encroachment into the sphere of privacy, which implies a violation of intimacy that exceeds the usual threshold of tolerance in social relations. In addition to making the recording itself, the act includes its further disposal, i.e. handing over, showing or otherwise enabling third parties to become familiar with the recording. A more serious form of this offense exists when it is committed by an official in the performance of their duties, which further undermines trust in the legal and responsible exercise of public authority.

On the other hand, the criminal act of unauthorized publication and display of someone else's file, portrait and video from Article 145 of the Criminal Code represents a further stage of the violation of the right to privacy, aimed at unauthorized public disclosure or making available of personal content. The act of execution consists in publishing or displaying documents, portraits, photographs, films or phonograms without the consent of the authorized person, where, as with the previous act, it is necessary that such action leads to a noticeable encroachment on the personal life of the injured party. The protective object of this criminal offense includes not only privacy in the narrower sense, but also the right to control one's own personal data and content related to one's personality. The qualified form of the act is provided in the case when it is committed by an official in the performance of his duties, which indicates the increased social danger of such behavior and the need for its stricter criminal sanction.

Namely, the common constitutive element of these criminal acts is taking actions without the consent of the passive subject, which could be the basis for their limited application in the context of „deepfake” content. However, as the literature points out, this construction is only conditional, since the consequences produced by the creation and dissemination of „deepfake” pornographic material, as a rule, exceed the intensity of the injury associated with „classic” forms of unauthorized photography or publication of authentic recordings. It is especially emphasized that the contents are both inauthentic and highly believable, and that their pornographic nature inevitably leads to serious damage to the reputation and personal integrity of the persons shown (Mrvić Petrović, 2024, p. 17).

Bearing in mind the legal definition of sexual harassment from Article 182a of the Criminal Code, it can be concluded that the abuse of artificial intelligence for the purpose of creating and distributing „deepfake” pornographic content would be most appropriate to be legally qualified as this criminal offense, since such behavior, although technologically mediated, undoubtedly represents a form of unwanted, humiliating and offensive behavior that encroaches on the dignity of the person in the sphere of sexual life and creates a hostile environment for damaged person.

The criminal act of sexual harassment from Article 182a of the Criminal Code represents a special form of protection of personal dignity in the sphere of sexual life, criminalizing various forms of unwanted sexual behavior. The act of execution includes any verbal, non-verbal or physical action that aims at or represents a violation of the dignity of another person in this intimate sphere, where it is important for the existence of the act that such behavior causes fear or creates a hostile, humiliating or offensive environment. This normatively covers a wide range of behavior, from inappropriate comments and gestures to physical contact, if the specified qualifying conditions are met. A more serious form of crime exists when the act is committed against a minor, which reflects the need for enhanced criminal protection of this particularly sensitive category. The specificity of this criminal offense is also reflected in the procedural legal regime of prosecution, since for the basic form of the offense, the proceedings are initiated at the proposal of the injured party, which indicates respect for his will and autonomy regarding the protection of the personal sphere. However, this procedural regime of criminal prosecution represents an additional obstacle in qualifying the abuse of artificial intelligence for the purpose of creating and distributing „deepfake” pornographic content as a criminal offense of sexual harassment, since it significantly complicates the realization of effective criminal legal protection. Namely, in practice it is almost impossible for the injured party to independently identify the perpetrator and provide relevant evidence, especially bearing in mind the complexity of the digital environment and the need for the application of specialized methods of digital forensics, which as a rule are available only to competent state authorities (Mrvić Petrović, 2024, p. 17).

In the context of modern technological challenges, the abuse of artificial intelligence for the purpose of creating and distributing „deepfake” pornographic content, when minors are involved in such actions, can be legally qualified as a criminal offense under Article 185 of the Criminal Code - displaying, obtaining and possessing pornographic material and exploiting a minor for pornography. This criminal offense encompasses a wider range of actions aimed at protecting minors from sexual exploitation, including both making pornographic content available to a minor, as well as using it for the production of such material, as well as obtaining, possessing and distributing content resulting from the exploitation of a minor. The legal definition of pornographic material created by the exploitation of a minor also includes visual representations of simulated sexually explicit behavior, which makes it possible to include in the framework of this criminal offense „deepfake” content that faithfully portrays a minor in such situations, regardless of the fact that they are not the result of the actual participation of that person in such behavior. It is particularly important that the law recognizes and sanctions not only the production and distribution, but also the conscious access to such content through information technologies, which seeks to ensure comprehensive criminal protection of minors against various forms of digitally mediated sexual exploitation.

Current solutions in the Criminal Code do not provide an adequate level of protection, since legal protection is achieved indirectly, through an extensive interpretation of existing provisions, which results in its partiality and insufficient comprehensiveness (Dimovski, 2023, p. 172).

Based on the observed normative deficiencies and limitations in the application of existing incriminations, there is a need for explicit criminal law regulation of the abuse of artificial intelligence for the purpose of creating and distributing „deepfake” pornographic content through the introduction of a special criminal offense. Such incrimination should be conceived in a way that respects the specifics of the digital environment, including the technical characteristics of generative technologies, the transnational character of the execution, as well as the complexity of evidence in cyberspace. At the same time, it is necessary to foresee an adequate procedural legal framework that would enable effective detection and prosecution of perpetrators, without excessive reliance on the initiative of the injured party, especially bearing in mind his factual inability to provide key digital evidence on his own (Matijašević, Bingulac and Marinković, 2024, p.18). The normative solution should provide comprehensive protection of both minors and adults, with a clear definition of prohibited actions, including the creation, distribution and acquisition of such content, which would contribute to the improvement of the effectiveness of criminal law protection in conditions of accelerated technological development.

Bearing in mind the technological nature of digitally generated pornographic content, in addition to the challenges regarding its criminal qualification and the protection of injured persons, there are also other challenges related to the identification of victims, bearing in mind that such content often involves combining the identities of several persons, i.e. the use of the image of one person with the body of another, without their consent. This raises the issue of multiple violations of personal rights, given that each of the persons involved may be affected by the unauthorized use of their identity or physical appearance. Additionally, in situations where the original material is protected by copyright, legal claims by copyright holders may arise, which further complicates the legal analysis and deviation in such cases (Meskys, Kalpokiene, Jurcys and Liaudanskas, 2020, p. 28)

Victimology and Psychological Aspects of Abuse

Consideration of the abuse of artificial intelligence in the creation of pornographic content cannot be limited exclusively to the normative framework, but also requires an analysis of its victimological and psychological implications. This phenomenon produces specific forms of victimization, given that victims are often exposed to unauthorized display in a particularly intimate and stigmatizing context, without the possibility of control over their own identity and its digital representation. The consequences of such actions go beyond the legal sphere, including serious psychological reactions, but also long-term negative effects on social and professional relationships. In this sense, understanding the position of the victims and the nature of the damage suffered is an important basis for designing adequate mechanisms for their protection and support.

Modern applications based on artificial intelligence significantly lower the technical barriers for creating manipulative explicit photos and videos, which makes these forms of abuse available to practically every user of digital technologies. As a consequence, the risk increases that any person, not only public

figures, will be depicted in pornographic content without their knowledge and consent, solely on the basis of previously available digital photographs. Such unauthorized digital exploitation represents a serious violation of the right to privacy, dignity and personal autonomy, with victims often suffering intense psychological consequences, including feelings of humiliation, shame and loss of control over their own identity. An additional problem is the fact that existing legal frameworks in many legal systems still do not provide sufficiently clear and effective protection mechanisms, which can deepen the feeling of legal insecurity and secondary victimization among victims (Delfino, 2019, p. 890).

An additional dimension of the social danger of the abuse of artificial intelligence in the creation of pornographic content is represented by its rapid and difficult to control spread through social networks and digital platforms. Once posted, content can be duplicated, shared and redistributed multiple times, thus deepening and prolonging the victimization of the victim. Bearing in mind that the algorithmic logic of social networks favors the rapid circulation of visual content, the harmfulness of this phenomenon is not exhausted by the mere creation of content without consent, but is additionally intensified by its dissemination in the digital space (Tobing and Yuli, 2026, p. 1302).

An increasing number of empirical studies confirm the extremely unfavorable impact of the abuse of artificial intelligence on the mental health of victims. The consequences are particularly pronounced in cases where artificial intelligence is misused to create pornographic content, since such forms of victimization lead to an increased level of anxiety and depression, the development of various forms of addiction, as well as to the impairment of the victims' self-esteem. At the same time, research indicates the existence of gender differences, whereby women in such situations show a higher level of emotional and psychological distress compared to men. These findings further emphasize the need for the development of gender-sensitive measures in the field of mental health, in order to ensure more effective protection of particularly vulnerable social groups (Sharma and Malik, 2026, p. 4).

Minors are a particularly vulnerable social group, since the consequences of the misuse of artificial intelligence in the creation of pornographic content are often particularly pronounced for them and can permanently affect psychological development and quality of life in adulthood. Prolonged and multiple victimization can lead to intense feelings of guilt, shame and humiliation, as well as to anxiety, depression, sleep disorders, a damaged image of one's own body and identity, difficulties in establishing healthy emotional and partner relationships, and even to self-harm and suicidal thoughts. At the same time, exposure to such content increases the risk of further manipulation, harassment and sexual exploitation, with serious consequences for social adjustment, psychosexual development and understanding of the limits of acceptable sexual behavior (Krishna Borah, Ramaswamy and Seshadri, 2025, p. 110). An additional form of secondary victimization is reflected in the exposure of minor victims to offensive, humiliating and sexually explicit comments on such content in the digital space, which intensifies the psychological consequences and deepens the feeling of stigmatization and social isolation (Petrović, 2023, p. 96).

Bearing in mind the seriousness of the psychological consequences that such forms of digital victimization can cause, it is necessary to provide victims with timely, continuous and multidisciplinary psychological support aimed at overcoming trauma, strengthening the sense of security, preserving self-esteem and preventing long-term consequences for mental health.

The wide availability of sexually explicit content generated by artificial intelligence raises numerous psychological, ethical and social issues. Continuous exposure to such content can lead to a reduced sensitivity to intimacy, the formation of unrealistic expectations in partner relationships and a weakening of the emotional response to real interpersonal relationships. At the same time, excessive use of such materials can encourage the development of behavioral patterns similar to pornography addiction. In addition to individual consequences, the normalization of synthetic explicit content can contribute to the relativization of the importance of privacy, consent and sexual autonomy, which opens up broader questions about the transformation of social values and standards in the digital age (Deckker and Sumanasekara, 2025, p. 627). Therefore, in addition to the consequences suffered by the immediate victims, this type of content also produces broader social implications that go beyond the individual level of victimization.

In order to prevent the misuse of modern digital technologies, there is a need to improve educational approaches through the introduction of education about sexuality and the development of healthy interpersonal relationships, while at the same time strengthening digital literacy. Such an approach contributes to the understanding of the limits of privacy, the importance of consent and the recognition of potential risks, which would reduce the space for misuse of these technologies in the long term (Di Silvestro

and Iurissevich, 2024, p. 189).

Raising awareness about the possibilities of misuse of artificial intelligence for these purposes can have a significant preventive effect. However, the findings indicate that such activities do not necessarily lead to the improvement of the ability to recognize „deepfake” content, but in certain cases can produce a counter-effect, manifested through an increase in general uncertainty, anxiety and mistrust in digital information. In this context, the simultaneous development and strengthening of trust in authentic and verified content is of particular importance (Birrer and Just, 2025, p. 6829).

Students' Perception of The Abuse of Artificial Intelligence for Pornographic Purposes

In order to assess the attitudes, level of information and perception of abuse of artificial intelligence for the purpose of creating pornographic content, especially in the context of victimization and potential psychological consequences for the victims, an empirical study was conducted among the student population. The importance of such research is reflected in gaining insight into the way students recognize and understand this form of digital abuse, as well as in the possibility of a better understanding of the social perception of the phenomenon, which can contribute to the improvement of preventive, educational and criminal protection mechanisms. At the same time, the results of the research can serve as a basis for a critical review of the existing criminal legal framework and consideration of the need for its adaptation to the challenges brought by the abuse of artificial intelligence in the field of sexually explicit digital content.

Research Sample

The research sample consists of 109 undergraduate students of the Faculty of Law for Commerce and Judiciary in Novi Sad, University Business Academy in Novi Sad. Participation was voluntary and anonymous. 47 male students (43%), 60 female students (55%), and 2 students who did not make a statement have participated in the research. The biggest deviation was observed among second-year undergraduate students, where close to 68% were female students.

In the next chart is shown the distribution of students - respondents by gender and year of study (Chart 1).

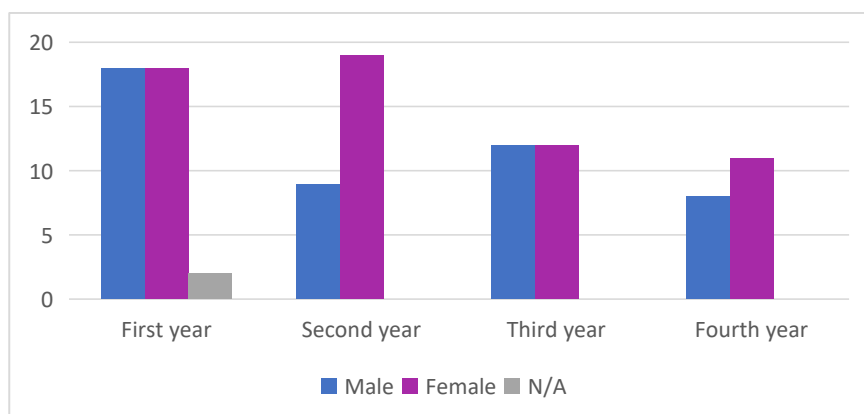


Chart 1. Surveyed students by gender and year of study. Source: Authors' search

Research Instrument

Pre-prepared and printed survey - questionnaire was used to collect data. Data were collected in the period March-April 2026. The survey contains questions related to students' familiarity with the concept of deepfake technology and the possibility of abusing artificial intelligence to create pornographic content featuring a real person without consent; familiarity with cases where artificial intelligence was used to create pornographic content utilizing the image of a real person without consent; students' opin-

ions about the social dangerousness of the creation of pornographic content using artificial intelligence without a person's consent; students' opinion to what extent this kind of abuse can cause serious negative psychological consequences for the victim; should the creation of pornographic content using artificial intelligence without a person's consent be specifically regulated by criminal legislation and finally, students' opinions regarding measures that would contribute the most to preventing the misuse of artificial intelligence for these purposes.

Research Results

Firstly, students' familiarity with the concept of deepfake technology and the possibility of abusing artificial intelligence to create pornographic content featuring a real person without their consent was examined. 57 respondents answered that they were fully familiar, 31 were partially familiar, and 21 were not familiar (Chart 2 and Chart 3).

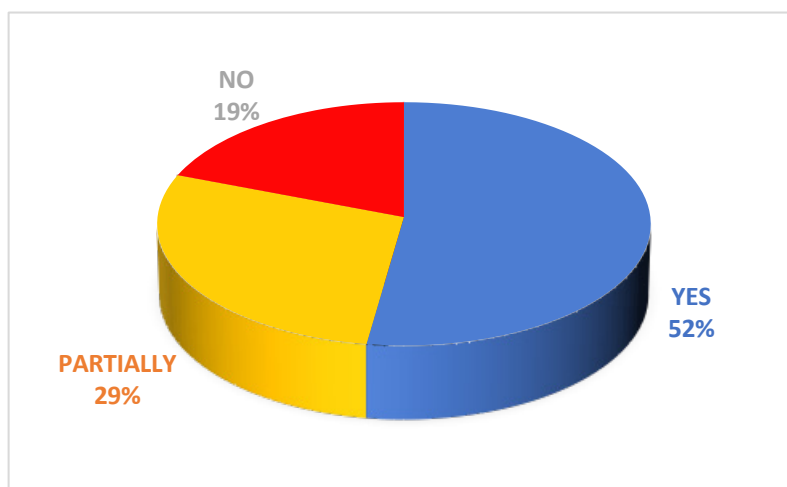


Chart 2. Students' familiarity with the concept of deepfake technology and the possibility of abusing artificial intelligence to create pornographic content of a real person without consent
Source: Authors' search

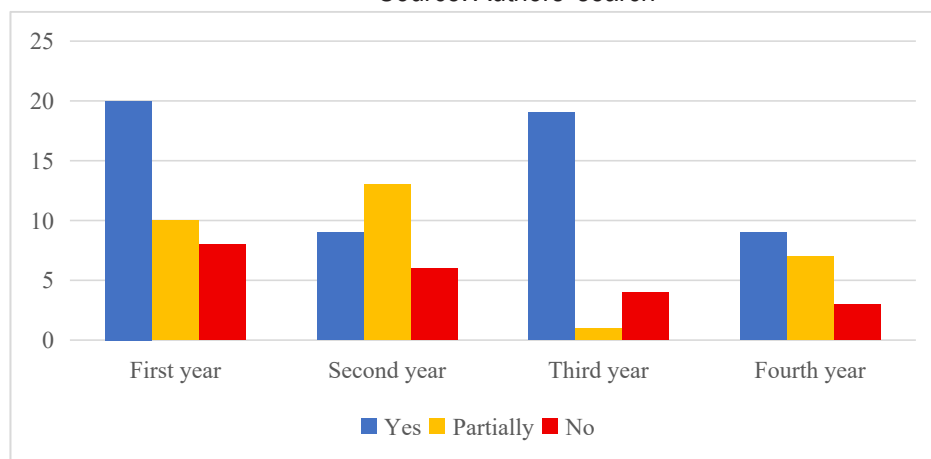


Chart 3. Students' familiarity (by the year of study) with the concept of deepfake technology and the possibility of abusing artificial intelligence to create pornographic content of a real person without consent.
Source: Authors' search

Then, 56% of surveyed students have heard or come across cases where artificial intelligence was used to create pornographic content utilizing the image of a real person without consent (Chart 4 and Chart 5).

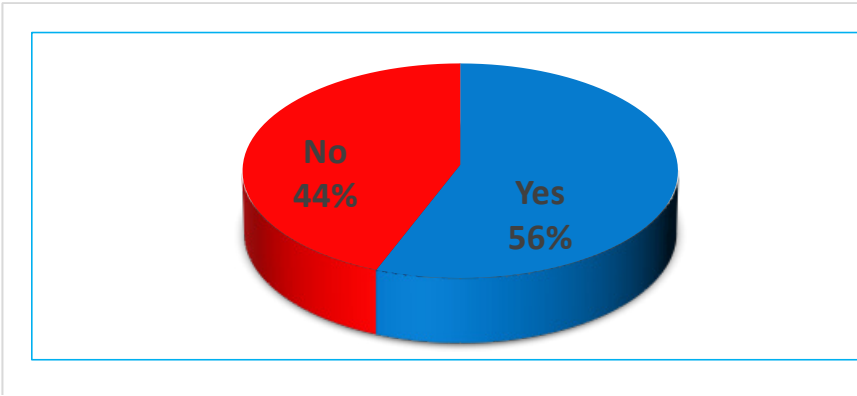


Chart 4. Students that have heard or come across cases in which artificial intelligence was used to create pornographic content utilizing the image of a real person without consent. Source: Authors' search

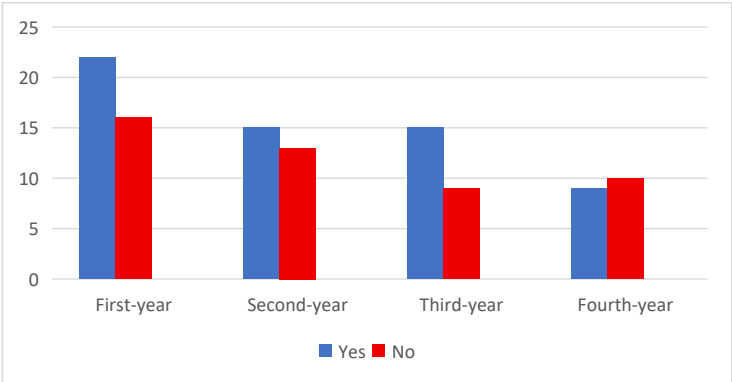


Chart 5. Students (by the year of study) that have heard or come across cases in which artificial intelligence was used to create pornographic content utilizing the image of a real person without consent. Source: Authors' search

For surveying students' opinions about the social dangerousness of the creation pornographic content using artificial intelligence without a person's consent, scale of risks, ranging from very dangerous to not dangerous was used (Chart 6 and Chart 7).

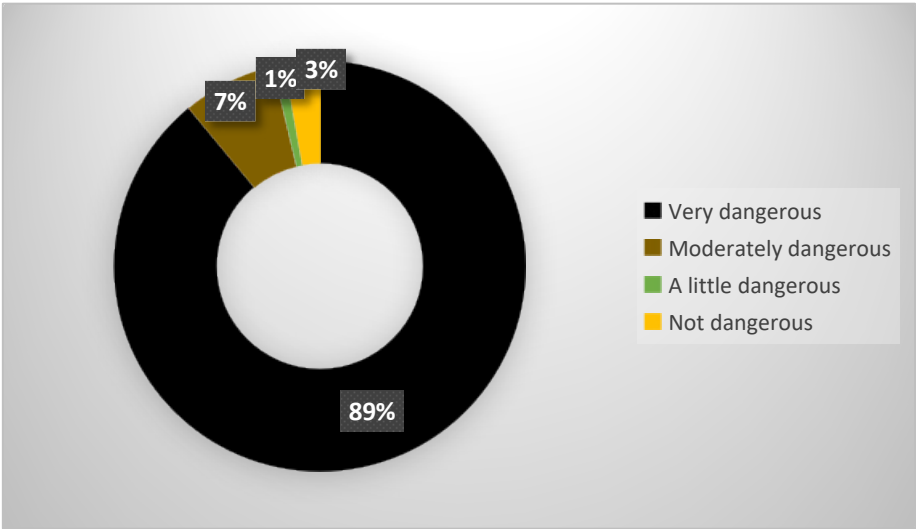


Chart 6. Students' opinions about the social dangerousness of the creation pornographic content using artificial intelligence without a person's consent. Source: Authors' search

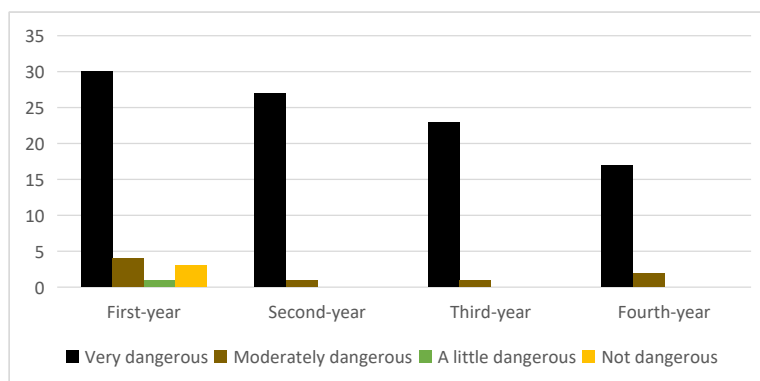


Chart 7. Students' opinions (by the year of study) about the social dangerousness of the creation pornographic content using artificial intelligence without a person's consent. Source: Authors' search

The next question in the survey dealt with the students' opinion to what extent this kind of abuse can cause serious negative psychological consequences for the victim (eg stress, anxiety, reputational damage). A range scale from severe to no serious negative psychological consequences for the victim was given here (Chart 8).

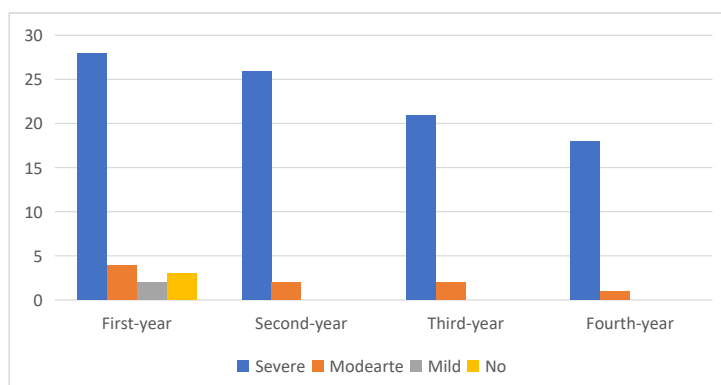


Chart 8. Students' opinion about the extent of serious negative psychological consequences for the victim this kind of abuse can cause. Source: Authors' search

Should the creation of pornographic content using artificial intelligence without a person's consent be specifically regulated by criminal legislation was the following question in the survey . Yes/no/not sure answers were given to students to express their opinions (Chart 9).

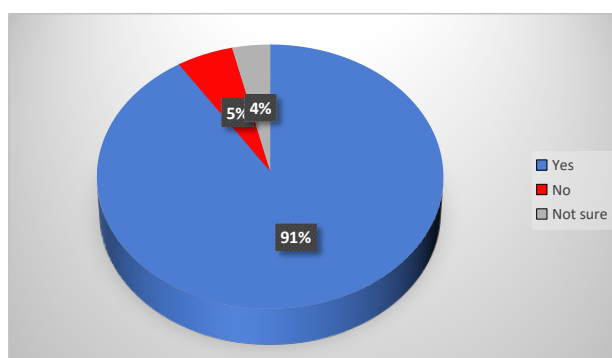


Chart 9. Students' opinion regarding the question whether creation of pornographic content using artificial intelligence without a person's consent should be specifically regulated by criminal legislation. Source: Authors' search

Finally, the last question asked in the survey was: What measures, in your opinion, would contribute the most in preventing the misuse of artificial intelligence for these purposes? The given answers were the following: stricter criminal sanctions law, greater digital platforms governance, education of internet users and development of technologies for detecting manipulated content (Chart 10).

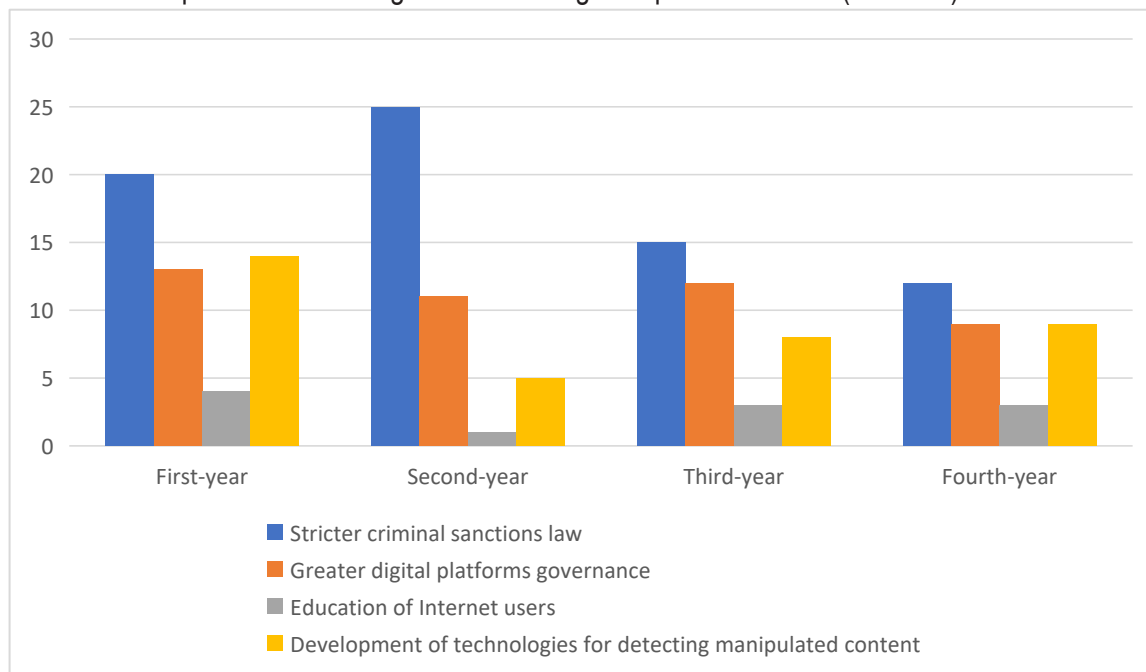


Chart 10. Students' opinion regarding the contribution in preventing the misuse of artificial intelligence

Source: Authors' search

From all of the above mentioned, we can conclude that the surveyed students are aware of the dangers, but are not sufficiently familiar with the concept of deepfake technology and the possibility of artificial intelligence to create pornographic content by using an image of a real person without consent.

Regarding students' familiarity with the concept of deepfake technology and possibility of AI to create pornographic content featuring a real person without consent, the majority of respondents are familiar (52%), 29% are partially familiar (in the case of the second-year students, partial familiarity is the majority). It is important to emphasize here that a large percentage of respondents - 19%, answered that they were not familiar.

Also, a large percentage - 44% of surveyed students have not heard or come across cases where artificial intelligence was used to create pornographic content utilizing the image of a real person without consent.

Students' opinions about the social dangerousness of this creation are that it is very dangerous (89%) and students of all study years found severe negative psychological consequences for the victims.

A large percentage of surveyed students (91%) believe that this matter should be regulated by criminal legislation and in accordance with that, they believe that stricter criminal sanctions law would contribute the most in preventing the misuse of artificial intelligence for these purposes.

Conclusion

The misuse of artificial intelligence in the creation of pornographic content is emerging as a complex social and legal phenomenon which, due to its technological sophistication, transnational character and pronounced victimological implications, exceeds the limits of traditional criminal law responses and requires interdisciplinary consideration. The rapid development of generative technologies points to the limitations of the existing normative framework, since the protection against digitally generated sexually explicit content created without consent is achieved to a significant extent indirectly and through extensive interpretation of existing incriminations, which calls into question its completeness and effectiveness in the modern digital environment. At the same time, the pronounced recognition of the social danger of this phenomenon and its potentially serious psychological consequences indicates a growing need for a sys-

temic approach to the protection of victims, especially bearing in mind that the possibility of rapid, massive and difficult-to-control dissemination of content through digital platforms further deepens and prolongs victimization. In this sense, an adequate response to the subject phenomenon presupposes not only the normative improvement of criminal law protection, but also the development of coordinated preventive, educational and psychological-supporting mechanisms aimed at protecting the privacy, dignity and mental integrity of persons exposed to these forms of digital abuse.

The results of the conducted empirical research indicate the existence of a pronounced awareness of the student population about the social danger of the abuse of artificial intelligence for the purpose of creating pornographic content without consent, as well as the seriousness of the potential psychological consequences that such forms of digital victimization can produce for victims. However, despite the dominant recognition of the harmfulness of this phenomenon, the research findings indicate a certain degree of insufficient information among respondents regarding the concept of deepfake technology and the possibility of artificial intelligence to generate sexually explicit content using the identity of a real person without their consent, which confirms the fact that a significant percentage of students express partial or complete ignorance of the issue in question. Additionally, the fact that a significant number of respondents did not encounter concrete cases of such abuse may indicate insufficient visibility and social recognition of this form of digital violence, despite its growing technological availability and potentially serious consequences for victims. At the same time, the high level of agreement of respondents regarding the need for criminal law regulation of this matter, as well as the perception of the importance of stricter criminal sanctions in the function of prevention, indicate the social justification of further normative consideration of the criminal law treatment of the abuse of artificial intelligence in the creation of pornographic content, with the parallel development of preventive and educational mechanisms aimed at improving digital literacy and protecting potential victims.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Institutional Review Board Statement

Not applicable.

Author Contributions

Conceptualization, J.M., M.P. and M.G.; methodology, J.M. and M.P.; software, M.G.; formal analysis, J.M., M.P. and M.G.; writing-original draft preparation, M.P. and M.G.; writing-review and editing, J.M. and M.P. All authors have read and agreed to the published version of the manuscript.

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Managerial Information Use and Innovation in Service Microenterprises: Implications for Learning, Competence Development, and Quality Improvement

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Abstract: Managerial learning and competence development are important for service microenterprises seeking to use business information effectively, adopt innovations, and improve their operations. This study examines managerial perceptions of information use, innovation, institutional support, and professional development needs in service microenterprises in Serbia, with particular attention to their implications for learning, competence development, and quality improvement. A descriptive survey was conducted from June to December 2024 using a convenience sample of 224 owners, directors, managers, and other representatives of microenterprises located in three municipalities of Belgrade. Data were collected through a structured closed-ended questionnaire and analysed using descriptive statistics. Results show that innovation management was highly valued as a contributor to competitiveness, while technological processes and customer-oriented changes received particularly favourable assessments. Respondents associated innovation with market expansion, service quality, operational flexibility, and efficiency, but also identified financial, technological, and knowledge-related constraints. Institutional support was considered particularly important through financial incentives, assistance with technology acquisition, and access to financing. Training preferences focused on export activities, public procurement, marketing and sales, quality standards, and financial management, indicating demand for practically applicable managerial competencies. Business information was also recognized as relevant to successful operations. Overall, the findings indicate that quality improvement in service microenterprises can be supported by strengthening managerial competencies, information use, innovation capacity, and continuing professional learning.

Keywords: managerial learning, managerial competencies, business information use, innovation management, quality improvement, service microenterprises.

Introduction

Quality improvement has become one of the main strategic priorities for service microenterprises operating in increasingly dynamic and uncertain business environments. In such conditions, sustainable organizational performance depends not only on the implementation of formal Quality Management Systems (QMS), but also on managers' ability to acquire, interpret, and effectively use relevant business information, support informed decision-making, encourage innovation, and continuously improve organizational practices. Recent studies indicate that the effectiveness of innovation processes depends substantially on the quality of managerial decision-making, which is strongly influenced by the availability, interpretation, and application of relevant information (Holubčík et al., 2024). At the same time, quality management and organizational learning are increasingly recognized as complementary management approaches that jointly support continuous organizational improvement and long-term competitiveness (Tajouri et al., 2025).

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Quality Management Systems (QMS), supported by the application of international ISO standards, provide organizations with a structured framework for improving quality, increasing operational efficiency, and strengthening long-term competitiveness. Beyond standardization, effective implementation of QMS requires the integration of managerial practices that support continuous improvement, organizational adaptability, and innovation. In service organizations, sustainable business performance depends on management's ability to adapt organizational processes to continuous environmental, technological, and market changes (Bogetić et al., 2018). Successful implementation of QMS also requires commitment and support at all managerial levels, since managers play a central role in initiating organizational change and encouraging innovation. Timely and reliable business information represents an important trigger for organizational change, informed managerial decision-making, and business efficiency (Bourke and Roper, 2017; Holubčík et al., 2024). Consequently, high service quality increasingly depends on managers' ability to combine quality management principles with innovation, informed decision-making, and continuous organizational improvement.

In increasingly competitive and uncertain business environments, effective risk management represents an important component of quality management because it enables organizations to identify potential threats, reduce operational uncertainty, and respond more systematically to unexpected changes (Weckenmann et al., 2015; Ahmad et al., 2017). In service organizations, risk management should be integrated with quality standards and continuous improvement practices rather than treated as a separate managerial activity. Such integration can support more responsible decision-making, strengthen organizational adaptability, and improve the organization's ability to respond to changing customer and market requirements.

Continuous improvement in service enterprises requires not only the application of quality management concepts and techniques, but also the continuous development of employee and managerial competencies. Contemporary quality management increasingly relies on a broad set of competencies, including human, methodological, conceptual, and contextual capabilities, which enable managers and employees to implement quality principles effectively and respond to changing organizational requirements (Martin et al., 2021). In small and medium-sized enterprises, successful implementation of TQM also depends on leadership commitment, employee engagement, and the ability to adapt quality management practices to organizational characteristics, thereby strengthening competitiveness, operational efficiency, and sustainable performance (Masudin et al., 2025). At the same time, growing customer expectations continue to increase the need for high-quality services, cost efficiency, and shorter service delivery times, which further strengthens the role of continuous improvement in contemporary quality management practices.

In this context, quality improvement support systems have evolved from approaches primarily focused on perceived quality toward more integrated perspectives that incorporate human resources, organizational processes, information use, innovation, and continuous improvement (Weckenmann et al., 2015). Accordingly, contemporary approaches to quality management extend beyond the implementation of formal standards and increasingly emphasize the integration of managerial competencies, organizational learning, and the effective use of information to support innovation and continuous improvement (Martin et al., 2021; Tajouri et al., 2025).

Although previous studies have extensively examined quality management, innovation, and organizational performance, less attention has been devoted to understanding how managers in service microenterprises perceive the combined role of business information, innovation, institutional support, and quality improvement in organizational development. Recent evidence suggests that the successful use of information and communication technologies in SMEs depends not only on technological infrastructure but also on managerial capabilities, organizational readiness, employee competencies, and institutional support, all of which contribute to innovation and competitiveness (Yuwono et al., 2024). Accordingly, this study aims to examine how managers in Serbian service microenterprises assess the role of business information use, innovation, institutional support, and quality improvement, with particular attention to managerial learning and competence development. Empirical attention is directed towards innovation and competitiveness, the acceptance and perceived effects of innovation, forms of external support, training needs, and the importance attributed to business information in successful operations. By considering these dimensions jointly within the specific setting of service microenterprises, the research contributes to the existing literature by providing empirical insight into their relevance for managerial learning, competence development, and quality improvement.

Theoretical Background

Quality improvement in service organizations is increasingly recognized as a multidimensional process that extends beyond the implementation of formal quality standards. Contemporary approaches emphasize the importance of integrating quality management practices with managerial decision-making, organizational learning, innovation, and the effective use of business information. In service microenterprises, these elements are particularly important because limited organizational resources increase the need for competent management, continuous learning, and institutional support. Accordingly, the theoretical background of this study is organized around four interrelated themes: Quality Management Systems, managerial information use and decision-making, organizational learning and managerial competencies, and institutional support for quality improvement.

Quality Management Systems and continuous improvement

The ISO 9000 family of standards establishes a widely accepted basis for the development and operation of quality management systems. Its practical value, however, does not lie solely in formal compliance with prescribed requirements. The effects of QMS implementation also depend on how quality principles are incorporated into everyday organizational practices, managerial commitment, and the way procedures are actually applied. Evidence from ISO 9001-certified organizations shows that organizational commitment and the consistent application of procedures are closely associated with the development of quality culture, which in turn contributes to operational performance ([Bakhtiar et al., 2023](#)).

In practice, a QMS brings together quality objectives, process management, leadership, strategic planning, resource allocation, performance monitoring, and the regular review of organizational activities. Continuous improvement is embedded in this process through the Plan–Do–Check–Act (PDCA) cycle, which links planning and implementation with evaluation and corrective action. For small and medium-sized enterprises, these elements cannot simply be transferred from larger organizations without adjustment; they need to reflect available resources, organizational capabilities, and the specific context in which the enterprise operates ([Susanto et al., 2026](#)).

Beyond formal systems and procedures, the successful implementation of quality management also depends on the development of a strong quality culture. Recent research emphasizes that quality culture is shaped by organizational values and the behaviours through which these values are expressed in everyday practice. Greater alignment between organizational values and employee behaviours strengthens quality culture, facilitates continuous improvement, and enhances organizations' ability to adapt to changing internal and external conditions ([Fundin et al., 2025](#)).

Within the ISO 9000 framework, quality management is approached through a combination of customer orientation, leadership, employee participation, process management, continuous improvement, evidence-based decision-making, and effective relationship management. Rather than functioning as isolated principles, these elements provide an integrated framework for managing quality and supporting organizational development across different operational contexts. Contemporary research further suggests that the effectiveness of QMS depends not only on compliance with formal requirements but also on managerial competencies, organizational learning, and the effective acquisition and use of business information, which together support innovation and long-term organizational performance ([Martin et al., 2021](#); [Tajouri et al., 2025](#)).

Managerial information use and decision-making

Effective quality management depends not only on standardized procedures and organizational processes but also on managers' ability to acquire, interpret, and use relevant business information. In dynamic business environments, informed decision-making enables organizations to respond more effectively to changing customer requirements, technological developments, and competitive pressures. The quality of managerial decisions increasingly depends on the availability of reliable information and managers' capability to transform that information into appropriate organizational actions. Consequently, effective information use has become an important prerequisite for innovation, continuous improvement, and sustainable organizational performance ([Holubčík et al., 2024](#)).

Managerial decision-making represents a critical component of quality improvement because

organizational performance increasingly depends on managers' ability to transform available information into effective organizational actions. Recent research indicates that business analytics has become an important source of information for monitoring organizational performance, evaluating results, and implementing corrective actions. However, strategic decisions are rarely based solely on analytical information. Managers also combine business analytics with professional experience, stakeholder perspectives, and expert knowledge to support long-term planning and organizational development (Orjatsalo et al., 2025).

The effective use of information is particularly important in small and medium-sized enterprises, where managerial decisions are often made under conditions of limited financial, technological, and human resources. Recent evidence indicates that the successful adoption of information and communication technologies depends not only on technological infrastructure but also on managerial capabilities, organizational readiness, employee competencies, and institutional support (Yuwono et al., 2024). Strengthening these organizational capabilities supports more informed managerial decision-making, facilitates the implementation of quality management practices, and contributes to continuous quality improvement in service organizations.

Organizational learning, managerial competencies, and innovation

Organizational learning is increasingly recognized as one of the key mechanisms through which quality management contributes to continuous improvement. Rather than representing separate management approaches, Total Quality Management (TQM) and organizational learning reinforce one another by promoting knowledge sharing, employee involvement, problem-solving, and continuous process improvement. Recent research suggests that these approaches should be viewed as complementary because they jointly support organizational adaptability, innovation, and long-term competitiveness (Tajouri et al., 2025).

Managerial and employee competencies play a central role in the successful implementation of quality-related activities. Contemporary approaches emphasize that quality management requires a combination of human, methodological, conceptual, and contextual competencies, enabling managers to integrate quality principles into everyday organizational practices. Beyond technical knowledge, quality management professionals are expected to facilitate collaboration, support organizational change, communicate effectively, and promote a culture of continuous improvement. Developing these competencies strengthens organizational learning and enhances the organization's capacity to achieve sustainable quality improvement (Martin et al., 2021).

Organizational learning and managerial competencies provide the foundation for innovation and improved organizational performance. Empirical evidence indicates that organizations with stronger learning capabilities are more likely to develop innovative practices and achieve higher performance levels. Organizational learning enables managers to recognize changing customer needs, adapt organizational resources, and support continuous innovation, thereby strengthening organizational adaptability and long-term competitiveness. Furthermore, organizations that integrate organizational learning with customer-focused strategies are better positioned to improve organizational performance by responding more effectively to dynamic market conditions (Yuliansyah et al., 2021).

Institutional support, communication, and quality improvement

Institutional support is particularly relevant for service microenterprises operating with limited financial, technological, and organizational resources. Access to funding, technology, training opportunities, and professional networks can help these enterprises strengthen quality-related practices and build greater capacity for innovation. Evidence also suggests that sustainable improvements in quality and business performance are shaped by the interaction between internal capabilities and the wider support environment in which firms operate (Masudin et al., 2025).

Institutional support is most effective when combined with organizational efforts to develop managerial capabilities, employee competencies, and innovation-oriented practices. Access to appropriate technologies, training opportunities, and collaborative networks enables organizations to strengthen quality management processes, improve operational efficiency, and respond more effectively to changing market requirements. In small and medium-sized enterprises, these factors contribute to building organizational resilience and creating favourable conditions for sustainable quality improvement (Yuwono et al., 2024; Masudin et al., 2025).

Within quality management, communication serves as a practical link between planned procedures and their implementation in everyday work. When information is exchanged clearly and on time, responsibilities are easier to coordinate and quality-related decisions can be made with less delay. Inter-organizational communication can significantly influence the relationship between quality management practices and project performance, indicating that the benefits of quality initiatives depend partly on how effectively participants communicate during their implementation (Shah et al., 2022). This also highlights the importance of communication strategies that support employee involvement, clarify expectations, and facilitate coordinated action.

For service microenterprises, quality improvement is shaped by several closely connected managerial and organizational factors. Formal quality systems provide structure, while the practical effects of those systems depend on how managers use information, develop competencies, support learning, introduce innovations, communicate with stakeholders, and make use of available institutional support. These theoretical considerations provide the basis for interpreting the empirical findings on managers' assessments of innovation and competitiveness, innovation adoption and its perceived effects, institutional support, training needs, and the importance of business information for successful operations. Viewed together, these areas also allow the findings to be considered from a learning perspective, in which access to and use of information, competence development, and innovation represent interconnected aspects of managerial adaptation and quality improvement.

Materials and Methods

The empirical investigation was conducted to examine managerial perceptions of factors related to innovation, competitiveness, business information use, institutional support, and quality improvement in service microenterprises. A quantitative descriptive survey approach was adopted to provide an overview of managers' assessments of innovation practices and outcomes, external support mechanisms, and training needs relevant to managerial competence development. The study was designed to describe response patterns across the examined areas rather than to test causal relationships between variables.

Data collection

Data were collected between June and December 2024 through a structured questionnaire administered to owners, directors, managers, and other organizational representatives of service microenterprises located in the Belgrade municipalities of Voždovac, Čukarica, and Palilula. A convenience sampling approach was adopted, resulting in 224 valid responses. Given the organizational focus of the research, the sample was defined in terms of respondents' roles as representatives of service microenterprises and the business context in which they operated, rather than individual sociodemographic characteristics. Accordingly, the responses reflect a managerial and organizational perspective on the practices and support needs examined in the study. The survey was distributed through several communication channels, including e-mail, telephone communication, Viber groups, and direct personal contact. Respondents took part in the survey by choice, without providing information that would reveal their identity. Prior to responding, they received an explanation of the research purpose and were advised that the information obtained would remain confidential and be used solely for research.

Instrument development and data analysis

The questionnaire consisted of closed-ended questions covering business information use, innovation and competitiveness, technological and customer-oriented innovation, perceived effects of innovation, institutional support, and managerial training needs. Different response formats were used according to the content of individual question groups. Selected managerial assessments were measured using a five-point Likert scale, while other items used multiple-choice, three-category, or binary response formats. Frequencies (n) and percentages (%) were calculated for categorical and multiple-response items, while mean values (M) and standard deviations (SD) were additionally calculated for the five-point Likert-scale assessments. The results were presented in tables and figures to facilitate comparison across the examined areas.

Results

The research findings provide insight into the role of innovation, institutional support, and managerial practices in improving competitiveness and quality in service microenterprises. The results are presented through managers' assessments of competitiveness factors, innovation adoption, innovation outcomes, institutional support, and training needs.

Innovation and competitiveness

Innovation management was assessed positively in relation to the competitiveness of service microenterprises ($N = 224$, $M = 4.08$, $SD = 0.96$). Figure 1 shows that responses were concentrated in the two highest categories of the five-point Likert scale, "completely agree" and "mostly agree" ($n = 179$; 79.9%).

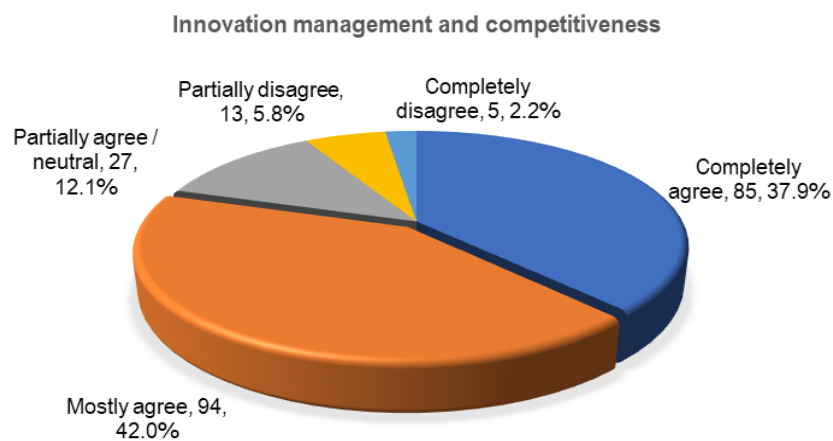


Figure 1. Managers' assessment of the contribution of innovation management to competitiveness

As shown in Table 1, the application of innovations and innovativeness emerged as the most prominent factor influencing the competitiveness of service microenterprises, followed by cost leadership and fragmented industries, while a focus on specific market niches was less frequently identified.

Table 1. Factors influencing competitiveness

Factor	n	%
Focus on specific market niches	30	13.4
Fragmented industries	51	22.8
Cost leadership	63	28.1
Application of innovations and innovativeness	96	42.9

Note. Respondents could select up to two answers ($N = 224$)

Technological innovations were generally well accepted among the surveyed managers. Full acceptance was higher for the introduction of new technological processes ($n = 141$; 62.9%) than for the introduction of new products or services ($n = 114$; 50.9%), as shown in Table 2.

Table 2. Acceptance of technological innovations in service microenterprises

Type of innovation ($N = 224$)	Fully accept		Partially accept		Do not accept	
	n	%	n	%	n	%
Introduction of a new product/service	114	50.9	65	29.0	45	20.1
New type of technological process	141	62.9	61	27.2	22	9.8

Sociological innovations directly related to customers and internal business processes received the strongest support. Full acceptance was highest for new ways of satisfying customers ($n = 164$; 73.2%) and changes in operating methods ($n = 150$; 67.0%), whereas lower levels of full acceptance were recorded for

new state measures regarding business conditions and new types of institutions within society (Table 3).

Table 3. *Acceptance of sociological innovations in service microenterprises*

Type of innovation (N = 224)	Fully accept		Partially accept		Do not accept	
	n	%	n	%	n	%
New ways of satisfying customers	164	73.2	25	11.2	35	15.6
Changes in operating methods	150	67.0	40	17.9	34	15.2
New state measures regarding business conditions	110	49.1	85	38.0	29	12.9
New types of institutions within society	87	38.8	76	33.9	61	27.2

Innovation effects were recorded across multiple dimensions of business performance. The most frequently reported effects were an expanded product and/or service assortment (n = 196; 87.5%), the withdrawal of obsolete products or services (n = 191; 85.3%), and entry into new markets and increased market share (n = 188; 83.9%). Improvements in product and service quality were also reported by a substantial proportion of respondents (n = 176; 78.6%), alongside effects related to operational flexibility, efficiency, and environmental performance (Table 4).

Table 4. *Effects of innovation in service microenterprises*

Achieved effects (N = 224)	n	%
Product and/or service assortment expanded	196	87.5
Existing products/services became obsolete and withdrawn	191	85.3
Entry into new markets and increase in market share	188	83.9
Product and service quality improved	176	78.6
Greater flexibility in production or service provision	171	76.3
Increased possibilities for higher production and/or service delivery	165	73.7
Greater production economy / lower costs per product	161	71.9
Environmental protection – reduction of harmful impacts	158	70.5

Institutional support for innovation

Managers assessed several forms of institutional support for encouraging innovation in service microenterprises. The highest level of complete agreement was recorded for incentives related to taxes and contributions (n = 164; 73.2%), followed by assistance in acquiring new technology and equipment (n = 137; 61.2%) and access to attractive credit lines (n = 125; 55.8%). Lower levels of complete agreement were recorded for finding strategic partners (n = 92; 41.1%) and cooperation with large companies (n = 85; 37.9%) (Table 5).

Table 5. *Institutional support for encouraging innovativeness*

Type of incentive (N = 224)	Completely agree		Partially agree		Do not agree	
	n	%	n	%	n	%
Cooperation with large companies	85	37.9	94	42.0	45	20.1
Finding strategic partners	92	41.1	72	32.1	60	26.8
Providing incentives (taxes and contributions)	164	73.2	54	24.1	6	2.7
Assistance in acquiring new technology and equipment	137	61.2	47	21.0	40	17.9
Attractive credit lines for financial resources	125	55.8	76	33.9	23	10.3

Training related to export issues received the highest level of preference (n = 204; 91.1%), followed by understanding and participation in public procurement (n = 184; 82.1%), marketing concepts and sales improvement (n = 181; 80.8%), and introduction to quality standards (n = 168; 75.0%). Financial management was also frequently selected (n = 157; 70.1%), whereas training for business beginners received the lowest level of preference (n = 62; 27.7%) (Table 6).

Table 6. Preferred ARRA training modules

Type of training (N = 224)	Included		Not included	
	n	%	n	%
Possibility of applying innovations	114	50.9	110	49.1
Training for business beginners	62	27.7	162	72.3
Preparation of business plans and cooperation with banks	119	53.1	105	46.9
Financial management	157	70.1	67	29.9
Export issues (for first-time exporters)	204	91.1	20	8.9
Marketing concepts and sales improvement	181	80.8	43	19.2
Electronic and information business operations	129	57.6	95	42.4
Introduction to quality standards	168	75.0	56	25.0
Education about the single European market	121	54.0	103	46.0
Understanding and participation in public procurement	184	82.1	40	17.9

The importance of information for successful business operations was assessed positively overall (N = 224, M = 3.40, SD = 1.41). Responses were most frequently concentrated in the two highest categories of the five-point Likert scale, “completely agree” and “mostly agree” (n = 119; 53.1%), as shown in Figure 2.

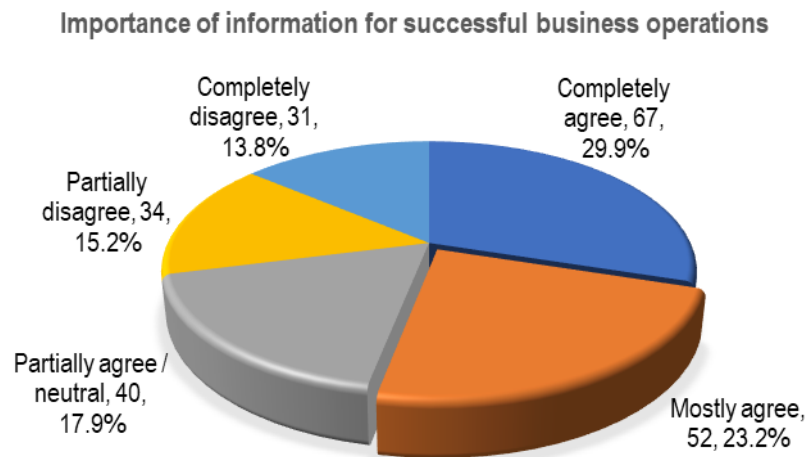


Figure 2. Managers' assessment of the importance of information for successful business operations

Discussion

Innovation emerges as a central element of competitiveness in service microenterprises. A high assessment of the contribution of innovation management to competitiveness (M = 4.08, SD = 0.96), together with the identification of innovation and innovativeness as the most frequently selected competitiveness factor, suggests that managers perceive innovation as an important component of competitive positioning. This result is consistent with earlier research emphasizing entrepreneurial creativity as an important source of new ideas and innovation in small enterprises (Walls et al., 2011). Subsequent research has shown that firms' capacity to acquire and apply knowledge can support innovative activity and contribute to improved business outcomes (Yuliansyah et al., 2021), while innovativeness has been found to exert a significant effect on MSME performance, both directly and through the development of marketing capabilities (Octasyva et al., 2022). More recent research also shows that stronger innovation capabilities are associated with better MSME performance, partly because they help firms build competitive advantage that translates innovation into improved business outcomes (Ziedan and Darmawan, 2026). Taken together, these results suggest that the competitive role of innovation in service microenterprises is reflected not only in the introduction of new products, services, or technologies, but also in the development of capabilities that enable

firms to learn, adapt, differentiate themselves, and sustain performance in changing market conditions.

A closer look at technological and sociological innovation provides further insight into how innovation is understood in service microenterprises. Although the introduction of new technological processes received stronger support than the introduction of new products or services, the highest level of acceptance across the examined forms of innovation was recorded for new ways of satisfying customers, followed by changes in operating methods. This pattern suggests that innovation in service microenterprises is not perceived exclusively in technological terms, but also through process improvement and customer-oriented practices. Such a broader understanding is consistent with the view of innovation as a complex process involving the generation and implementation of ideas and their adaptation to organizational and environmental requirements (Romero and Martínez-Román, 2012). More recent empirical evidence strengthens this interpretation. Customer orientation has been shown to positively affect SME performance, with innovation capabilities partially mediating this relationship (Bekata and Kero, 2025). The role of customer information and dynamic marketing capabilities in developing adaptive strategies and improving marketing performance in MSMEs has also been emphasized (Andreas and Hiong, 2025). In the context of the present study, the strong acceptance of technological processes, customer-oriented changes, and changes in operating methods points to the complementary role of technological, process, and customer-oriented innovation in strengthening the adaptability of service microenterprises.

Innovation effects identified in the present study further demonstrate its broader organizational relevance. Respondents associated innovation with an expanded product and service assortment, entry into new markets, improvements in service quality, greater operational flexibility, higher efficiency, and reduced harmful environmental impacts. This multidimensional pattern is consistent with recent systematic evidence showing that business model innovation in MSMEs contributes to economic performance, competitive advantage, environmental performance, and organizational resilience, while its effectiveness depends on organizational capabilities, managerial orientation, institutional conditions, and ecosystem support (Priya and Mathew, 2026). Recent research suggests that SMEs with stronger innovation capabilities are better positioned to improve their market results, partly because these capabilities help them develop advantages that strengthen their competitive position (Machado-Licona et al., 2026). Evidence from service organizations also links innovation-oriented practices with more favourable customer responses, particularly in highly competitive environments (Nwachukwu and Vu, 2022). The relationship between innovation and operational outcomes is also supported by evidence that core competencies, including innovation capability, resource management, and market responsiveness, contribute significantly to operational efficiency in MSMEs (Adeo, 2025). From a quality management perspective, TQM has been shown to enhance organizational performance while simultaneously strengthening innovation capability, which serves as an important mechanism linking quality management with performance and sustainability outcomes (Xu et al., 2026). Although this evidence comes from a manufacturing context, it still supports the view that quality practices, innovation capability, and performance are closely connected. In the present study, innovation was similarly associated with market expansion, customer-related outcomes, service quality, operational efficiency, and adaptability.

External support becomes especially important when these outcomes are considered alongside the resource constraints faced by service microenterprises. Stronger support for financial incentives, assistance in acquiring technology and equipment, and access to attractive credit lines suggests that managers primarily associate external support with overcoming financial and technological barriers to innovation. Limited resources can make it difficult for smaller firms to finance technological change, develop new capabilities, or pursue innovation without outside assistance. Access to finance, digital infrastructure, skills development, and appropriate regulatory arrangements have therefore been recognized as relevant elements of the wider environment supporting MSME transformation (Supriadi et al., 2023). Financial support also needs to be considered in relation to the changing ways in which smaller firms obtain funding, particularly as Fintech solutions create additional financing opportunities alongside public support measures (Abu et al., 2025). Recent systematic evidence also identifies resource constraints and institutional pressures among the factors shaping innovation-related strategic responses in MSMEs and emphasizes the importance of institutional conditions and ecosystem support for sustainability and resilience (Priya and Mathew, 2026). Empirical evidence additionally highlights the contribution of innovation and digital IT capabilities to MSME performance and the relevance of targeted financial incentives for strengthening technological adaptability and resilience (Probahudono et al., 2025). Viewed in this context, the preferences expressed

by managers in the present study indicate that institutional support is most valuable when it reduces resource barriers and enables service microenterprises to acquire the financial and technological capabilities required for innovation.

Managerial capability development represents another important dimension of support for service microenterprises. Preferences for training related to export activities, public procurement, marketing and sales, quality standards, and financial management indicate a pronounced orientation towards specialized knowledge that can be applied directly to market development and business operations. By contrast, the considerably lower preference for training aimed at business beginners suggests that respondents place greater value on function-specific competencies than on general introductory business knowledge. This pattern is consistent with earlier research showing that effective MSME management requires a combination of competencies related to financial decision-making, market development, interpersonal relations, and entrepreneurial activity, while gaps in these areas may create a need for continuous education and targeted business development programmes (Ng'ora et al., 2022). More recent empirical evidence confirms the broader importance of managerial capabilities, showing that managerial skills have a significant positive effect on MSME performance and supporting capability-building initiatives focused on managerial competence as a means of strengthening competitiveness and long-term performance (Indraprja et al., 2026). The particularly strong preference for export-related training can be interpreted in light of the capabilities required for successful international market participation. Export capability has been shown to depend on the development and interaction of technological, innovation, and entrepreneurial capabilities, with entrepreneurial orientation playing an important role in translating innovation capability into export readiness (Anggadwita et al., 2026). Complementary evidence indicates that an outward-looking entrepreneurial posture and the firm's ability to reconfigure resources and respond to change both contribute significantly to export performance, while the latter capability also mediates the relationship between entrepreneurial orientation and export outcomes (Sriboonlue and Sriboonlue, 2026). Viewed together, these results indicate that training needs in service microenterprises are closely associated with the development of specific managerial and strategic capabilities required for market expansion, operational decision-making, and improved business performance.

Information represents an additional managerial resource relevant to the development of service microenterprises. Although respondents generally recognized its importance for successful business operations, the mean assessment ($M = 3.40$, $SD = 1.41$) was more moderate than their assessment of the contribution of innovation management to competitiveness. This result may indicate that the value of information is recognized, but not necessarily translated into equally strong or systematic information-based managerial practices. Previous research has emphasized that effective managerial decision-making depends not only on access to information but also on managers' ability to interpret and use it in ways that support organizational learning and adaptation (Holubčík et al., 2024). In the MSME context, management accounting information systems have similarly been regarded as a means of providing timely, accurate, and relevant information to support managerial decision-making and reduce uncertainty (Siahaan et al., 2022). Access to technical information and external knowledge sources has also been identified among the factors relevant to the development of innovation capabilities in MSMEs (Kalathingal and Ambrammal, 2025). From this perspective, the importance attributed to information by respondents can be understood not only in terms of its immediate role in managerial decision-making but also as part of the knowledge base that enables service microenterprises to recognize changes, develop innovation capabilities, and adapt their activities to evolving business conditions.

Considered as a whole, the findings extend previous research by showing how innovation, managerial learning needs, information use, and institutional support are reflected simultaneously in the perceptions of managers in service microenterprises. Rather than treating these dimensions as separate aspects of business development, the present study reveals a distinctive pattern: strong recognition of innovation and its business effects is accompanied by substantial demand for specialized training and external support, while the importance assigned to business information remains comparatively more moderate. This contrast is particularly relevant because it points to a potential gap between innovation orientation and the information- and knowledge-related capabilities needed to support it. The contribution of the study therefore goes beyond confirming the importance of innovation for microenterprise development; it draws attention to managerial learning and competence development as elements that may help connect information use, innovation activities, and available institutional support with quality improvement. By documenting this

pattern in Serbian service microenterprises, the findings add context-specific empirical evidence to the literature on learning, innovation, and managerial capability development in small firms.

Conclusion

This study examined the role of innovation, managerial information use, and institutional support in the development and competitiveness of service microenterprises. The results indicate that innovation occupies a prominent position in managers' perceptions of competitiveness, with particular importance attributed to technological processes, customer-oriented changes, and improvements in operating methods. Innovation was also associated with a broad range of outcomes, including product and service renewal, market expansion, service quality, operational flexibility, efficiency, and environmental improvements. At the same time, respondents emphasized the importance of external support, particularly financial incentives, assistance in acquiring technology and equipment, and access to favourable financing, while their training preferences were strongly oriented towards export activities, public procurement, marketing, quality standards, and financial management. Information was also considered important for day-to-day business decisions, although respondents evaluated its contribution less strongly than innovation management.

The results therefore point to a broader set of conditions behind the development of service microenterprises. Innovation is important, but managers also rely on practical knowledge, usable business information, and external support when adapting to market changes. Opportunities for process improvement, differentiation, and market expansion are easier to pursue when firms have the necessary managerial skills and access to financial, technological, and institutional resources. Competitiveness therefore reflects more than innovation alone; it is also shaped by the capabilities available inside the enterprise and the support accessible from its wider environment. In this respect, the acquisition and managerial interpretation of relevant business information can support learning and competence development, facilitate innovation adoption, and ultimately contribute to quality improvement in service microenterprises.

From a practical perspective, the results point to the need for a more integrated approach to supporting service microenterprises. Managers should strengthen their capacity to identify and implement innovations, use relevant information in decision-making, and develop competencies related to market expansion, quality management, finance, and technology. Continuing managerial education and targeted training can support this process by linking competence development more closely to the practical needs identified by service microenterprises. At the institutional level, support measures should combine financial incentives and improved access to financing with assistance in technology acquisition, specialized training, and opportunities for business cooperation. Particular attention should be given to programmes that respond to the expressed needs of enterprises, especially those related to export activities, public procurement, marketing and sales, and quality standards. Aligning institutional support with these needs may enable service microenterprises to use their limited resources more effectively and strengthen their capacity for innovation and competitive development.

Interpretation of the findings requires some caution because of the sample coverage and research design. Data came from a convenience sample of service microenterprises in selected areas of Serbia, so the patterns observed here may not be representative of microenterprises operating elsewhere or under different economic and institutional conditions. A further constraint arises from the cross-sectional design: managerial perceptions were recorded at one point in time, without capturing possible changes in innovation practices, capabilities, or support needs over time.

Future research may extend the present findings by examining larger and more diverse samples across different service activities and geographical areas. Such an approach would allow similar patterns to be explored beyond the setting covered here. Longitudinal studies could trace changes in managerial practices, learning needs, and innovation capabilities as enterprises develop. Further research could also examine the relationships among business information use, managerial competencies, institutional support, innovation, and business performance using analytical approaches that allow these associations to be tested directly. Such evidence could provide a clearer understanding of how these factors interact through managerial learning processes in supporting quality improvement and the development of service microenterprises.

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The authors declare no conflict of interest.

Data Availability Statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Author Contributions

Conceptualization, A.P., A.S., and S.M.; methodology, A.P., A.S., and N.L.; formal analysis, A.P. and A.S.; investigation, A.P., A.S., N.L., and T.O.; data curation, A.P. and N.L.; writing—original draft preparation, A.P., S.M., and B.B.; writing—review and editing, A.S., S.M., T.O., and B.B.; visualization, A.P. and T.O.; supervision, S.M. and B.B. All authors have read and agreed to the published version of the manuscript.

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Barrett, KC, & Campos, JJ (1987). Perspectives on emotional development: II. A functionalist approaches to emotions. In Osofsky JD (Ed.), *Handbook of Infant Development* (2nd ed., Pp. 555-578). Oxford, England: Wiley.

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Adam, JJ, Paas, F, Teeken, JC van Loon, EM, Van Boxtel, MPJ, Houx, PJ, et al. (1998). Effects of age on performance and a finger-precuing task. *Journal of Experimental Psychology: Human Perception and Performance*, 24, pp. 870-883.

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Henry, W. A., III. (1990, April 9). Beyond the Melting Pot. *Time*, 135, 28-31.

- When we need to with the title of the article mention what kind of material it is then enclosed in square brackets after the title of the paper is printed by it is a brochure, video recording and the like.

Research and Training Center on Independent Living. (1993). Guidelines for reporting and writing about people with disabilities (4th ed.) [Brochure]. Lawrence, KS: Author.

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Schwarzer, R. (1989). Statistics software for meta-analysis [Computer software and manual]. Retrieved March 23, 2001, http://www.yorku.ca/faculty/academic/schwarze/meta_e.htm

- When the list reference is made to the work that is being prepared for the press, after the authors' names, in parentheses, listed in the press in English.

Zuckerman, M. Kieffer, SC (in press). Race differences in faceism: Does facial prominence imply dominance? *Journal of Personality and Social Psychology*.

- When the list of references cites a newspaper article without the author prints the name of the article, then the time of publication, then the title and number - in italics, and at the end of the page on which the article was published. If the title is long, we can shorten the optimum number of words by taking the first few words.

The new health-care lexicon. (1983, August / September). Copy Editor, 4, 1-2.

- If within the journal as publisher publishes a special issue as a monograph, it is necessary after heading indicate that it is a monograph.

Ganster, DC, Schaubroeck, J. Sime, WE, & Myers, BT (1991). The nomological validity of the Type A personality among employed adults [Monograph]. *Journal of Applied Psychology*, 76, 143-168.

- When an abstract or summary of the quote as the original source, after the title should be in parentheses to indicate that it is abstract.

Woolf, NJ, Young, SL, Famselow, MS, & Butcher, LL (1991). Map-2 expression in cholinceptive pyramidal cells of rodent cortex and hippocampus is altered by Pavlovian conditioning [Abstract]. *Society for Neuroscience Abstracts*, 17, 480 harvesters.

- Titles that are not in English, and we want them to be published in the journal in English, listed in their native language, and then in the square brackets give the title translation into English. In addition to the title, everything else remains the mother tongue.

Ising, M. (2000). Intensitätsabhängigkeit evozierter Potenzial their EEG: Sindh impulsive persons Augmenter stage Reducer? [Intensuty dependence and event related EEG potentials: Are impulsive individuals augmenters or reducers?]. *Zeitschrift für Différentiel und diagnostisch Psychology*, 21, 208-217.

- In the list of literature translated work following a text that we have a year of the original edition listed in parentheses at the end behind the publisher. When we quote in plain text, year of first publication and translation writing along with a slash between (eg. Laplace, 1814/1951).

Laplace, P. S. (1951). A philosophical essay on probabilities (FW Troscoott & FL Emory, Trans.). New York: Dover. (Original work published 1814)

- When the list of references cites a paper published in the Proceedings of the translated, italics will print the name of the collection at the end to add when it published the original.

Freud, S. (1961). The ego and the id. In J. Strachey (Ed. & Trans.), The standard edition of the complete psychological works of Sigmund Freud (Vol. 19, pp. 3-66). London: Hogarth Press. (Original work published 1923).

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Broadhurst, RG, & Maller, RA (1991). Sex offending and recidivism (Tech. Rep. No. 3). Nedlands: University of Western Australia, Crime Research Center.

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Vandenbos, G. Knapp, S., & Doe, J. (2001). The role of reference elements in the selection of resources by psychology undergraduates [Electronic version]. *Journal of Bibliographic Research*, 5, 117-123. Retrieved October 13, 2001, from <http://jbr.org/articles.html>

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8th GVU's WWW User Survey. (Od). Retrieved August 8, 2000, from http://www.cc.gatech.edu/gvu/user_surveys/survey-1997-10/

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Cuter, LD, Frölich, B., & Hanrahan, P. (1997, January 16). Twohanded direct manipulation on the responsive workbench. Paper presented at the 1997 Symposium on Interactive 3D Graphics. Abstract retrieved June 12, 2000, from <http://www.graphics.standard.edu/papers/twohanded/>

- Computer software listed noting computer software. Name of the software we write italics.

Miller, M. E. (1993). *The Interactive Tester (Version 4.0)* [Computer software]. Weastminster, CA: Psytek Service.

- Data downloaded from the website of the government or other official organization listed noting data file. The filename of the data listed in italics.

Department of Health and Human Services, National Center for Health Statistics. (1991). *National Health Provider Inventory: Home health agencies and hospices, 1991*. [Data file]. Available from the National Technical Information Service Web site, <http://www.ntis.gov>

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