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International Journal of Cognitive Research in Science, Engineering and Education

(IJCRSEE)

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
- Psycholinguistics and cognitive linguistics
- Forensic psychology and applied cognitive research
- Cognitive aspects of sport and physical culture
- 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
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- 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
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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

JCRSEE 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 IJCRSEE 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.

IJCRSEE 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.duplichecker.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 13 articles (9 Original researches and 4 Review articles). 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
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Social and Technological Drivers of Sustainable Manufacturing Performance: A Cognitive-Organizational Perspective

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Abstract: Sustainable manufacturing has become a strategic priority for organizations seeking to balance competitiveness with environmental and social responsibility. However, the successful implementation of sustainability initiatives depends not only on technological and economic factors but also on workforce competencies, organizational learning, and human-centered drivers. This study examines the cognitive and organizational determinants of sustainable manufacturing performance through the analysis of social, economic, environmental, and quality drivers in manufacturing organizations in the Republic of Serbia. Data were collected using a structured questionnaire administered to 153 employees in production-related positions. The research model integrates human, technological, and managerial dimensions of sustainability and evaluates their influence on six performance outcomes: environmental, social, economic, process, innovation, and stakeholder performance. Multiple regression analyses were applied to test the proposed relationships. The findings indicate that environmental and economic drivers exert the strongest positive effects on performance outcomes, while social drivers - reflecting employee engagement, training, and organizational culture - demonstrate moderate but significant influence. Quality drivers show mixed effects across performance domains. The results highlight the critical role of workforce involvement, knowledge development, and sustainability-oriented competencies in supporting organizational transformation toward sustainable manufacturing. This study contributes to the emerging cognitive-organizational perspective on sustainability by integrating human and technological drivers within a single empirical framework and providing evidence from a transition economy context.

Keywords: *sustainable manufacturing, cognitive-organizational drivers, organizational performance, workforce competencies, technological drivers, human factors.*

Introduction

Sustainable manufacturing is evolving as organizations adopt strategies to reduce waste, enhance efficiency, and align competitiveness with environmental and social responsibility (Karuppiah et al., 2024; Scharmer et al., 2024). The concept of sustainable manufacturing encompasses the integration of environmental management, social responsibility, and operational excellence into production processes to achieve long-term viability (Scharmer et al., 2024). However, despite theoretical advances, the empirical evidence on which drivers are crucial in the process of implementing sustainable manufacturing, especially in transitional economies, remains limited. Companies are increasingly under pressure to align competitiveness with responsibility toward the environment, employees, and society. Beyond technological investments and environmental initiatives, sustainable manufacturing increasingly depends on human and cognitive factors embedded within organizational systems. Employee competencies, sustainability awareness, continuous learning, and knowledge sharing practices shape the extent to which sustainability principles are adopted and operationalized in production environments. From this perspective, manufacturing transformation is not solely a technical process but also a cognitive and educational one, requir-

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ing the development of workforce capabilities aligned with sustainable and digital industrial paradigms. In transition economies, the pressure rises, as traditional industrial models must adapt to the requirements of sustainability and digital transformation (Karuppiah et al., 2024). Manufacturing organizations are, therefore, expected to integrate sustainability principles not only to meet regulatory demands but also to improve resilience, innovation capacity, and market reputation (Scharmer et al., 2024). Identifying drivers of sustainable manufacturing provides both theoretical and practical insights into how manufacturing organizations can align economic efficiency with environmental and social objectives (Karuppiah et al., 2024). Thus, this research aims to identify and analyze the key drivers that influence the implementation of sustainable manufacturing practices in production-oriented organizations, with a specific focus on the Republic of Serbia. Based on a comprehensive literature review, a list of factors that stimulate the adoption of sustainable practices in industrial systems has been developed. The research provides insights into the current state of sustainable manufacturing implementation within the Serbian manufacturing sector. Drivers influence the degree to which sustainable manufacturing practices are adopted, which in turn affects performance. Higher levels of drivers are expected to lead to stronger implementation and thus better outcomes across performance dimensions. The model allows for cross-domain effects, anticipating positive relationships across driver-performance pairs. While many explore drivers of sustainable practices in developed economies, fewer empirical investigations focus on transition economies or on multiple driver types simultaneously. This research examines social, economic, environmental, and quality drivers simultaneously in relation to multiple dimensions of organizational performance (social, economic, environmental, process, innovation, and stakeholder). This research addresses the gap by surveying manufacturing organizations in Serbia, encompassing operational, managerial, and supportive roles. This approach provides novel empirical evidence from a transitional economy. Thus, this research contributes by: (a) empirically validating a framework of sustainable manufacturing adoption; (b) testing the relative influence of distinct drivers on multiple performance outcomes; and (c) providing evidence from a country with limited prior research in this domain. Considering the research subject, objectives, and existing literature, the following research question has been formulated: “How do social, economic, environmental, and quality (technological) drivers influence sustainable manufacturing performance, from a cognitive-organizational perspective?”

Literature review

Achieving sustainability-oriented performance improvement requires a multidimensional approach that integrates organizational, technological, and human factors (Rosen and Kishawy, 2012). The idea has evolved in recent years from being solely ecological to encompassing environmental management in relation to innovation and operational excellence (Andronie et al., 2021). Manufacturing businesses are increasingly recognizing that sustainability is not just a moral or environmental requirement; it is also a business imperative. Resilience and long-term competitiveness are fueled by sustainability (Andronie et al., 2021). The internal and external factors that are essential for organizations to implement socially and environmentally responsible practices are represented by drivers in this framework. These drivers are typically divided into four groups based on a summary of earlier research: social, economic, environmental, and quality drivers. Each of these groups influences sustainability outcomes through specific mechanisms. These factors frequently work together to produce synergies that increase the overall impact on the organization. Social drivers underscore the importance of organizational culture, employee well-being, and human capital as the cornerstones of long-term success. Strong ergonomic work practices and a safety culture increase dependability, lower accident rates, and promote long-term results (Małysa and Gajdzik, 2020). Furthermore, ongoing human resource development and employee involvement improve environmental commitment and accountability (Lee et al., 2019; Madero-Gómez et al., 2023). Recent research emphasizes that sustainability implementation is strongly influenced by workforce knowledge structures, pro-environmental attitudes, and training systems that foster sustainability-oriented behavior. Learning organizations are more capable of integrating environmental practices into operational routines, as employees develop cognitive frameworks that support long-term ecological decision-making. Consequently, human capital development and sustainability education emerge as critical enablers of manufacturing transformation (Garavan et al., 2012; Wiek et al., 2011). Stakeholder engagement and corporate social responsibility (CSR) programs are two strong external drivers that promote environmentally friendly behavior (Afsar and Umrani, 2020). Organizations notice a greater alignment between social responsibility and organizational outcomes when employees actively participate in sustainability projects, particularly in emerging markets (Baykal and Divrik, 2023). Cost-cutting, energy efficiency, productivity gains, and innovation are all examples of economic drivers that enhance competitive advantage. According to empirical research, data-driven decision-making and predictive maintenance dramatically reduce waste, operational expenses, and downtime, enhancing sustainability and profitability (Polese et al., 2021; Mahfoud et al., 2024). Since businesses that utilize structured energy management techniques achieve quantifiable savings and a reduction in their environmental impact, energy efficiency remains a significant economic driver (Solnørdal and Foss, 2018). These factors also apply to supply chains: effective inventory control and logistics reduce waste and improve responsiveness (Panigrahi et al., 2024; Gibson, 2023). Due to their concrete and quantifiable nature, economic and environmental drivers typically have stronger and more consistent effects on performance outcomes, according to the literature (Madero-Gómez et al., 2023; Hariyani et al., 2023). Environmental drivers encourage businesses to adopt green innovation, eco-efficiency, and cleaner production practices to minimize their environmental impact. They frequently result from proactive environmental management, consumer expectations, or regulatory frameworks (Rosen and Kishawy, 2012; Andronie et al., 2021). With their clear routes to resource-efficient and low-carbon production, eco-innovation and circular economy concepts have taken center stage in contemporary manufacturing strategies (Chaurasiya and Singh, 2024). Sustainability initiatives are further aligned with market demand by the incorporation of green product design and rising consumer awareness (Bravo et al., 2022). Environmental performance is now recognized as being greatly enhanced by technological innovation, energy-efficient production systems, and the effective management of renewable resources (Fatma and Haleem, 2023; Panagiotopoulou et al., 2022). Developing internal green competencies also promotes continuous improvement and long-term capability building (Fatma and Haleem, 2023). Sustainability is closely linked to innovation and ongoing improvement driven by quality. Achieving environmental and social objectives without sacrificing process or product standards is made possible by combining quality management concepts with sustainable manufacturing (Abubakr et al., 2020). By coordinating sustainability objectives with competitiveness and customer value creation, innovation-oriented quality systems promote change (Cordova and Celone, 2019). Moreover, sustainable relationship management and customer-centric strategies that strengthen stakeholder trust and company reputation are examples of quality drivers that go beyond production (Ferrer-Estévez and Chalmeta, 2023). Together, these factors show that manufacturing sustainability is not only ecologically conscious but also operationally dependable, creative, and value-driven.

Materials and Methods

To investigate the impact of various factors on sustainable manufacturing performance in production-oriented organizations in Serbia, this study employed a quantitative, cross-sectional research design. This method was considered suitable for evaluating multiple relationships simultaneously and identifying trends across a wide range of industrial settings.

Data collection

To ensure widespread participation, a structured questionnaire was disseminated both electronically and in print to gather data. Employees from manufacturing companies across various industrial sectors, including food production, machinery, metal processing, and automotive components, provided a total of 153 valid responses. Because the respondents held a variety of professional roles, from managerial and administrative to technical and operational, the sample was representative of those directly involved in or supporting production processes. The survey was anonymous and voluntary to complete. Prior to their involvement, all participants were informed about the purpose of the study and the confidentiality of their responses, and they provided their informed consent. The study was conducted in accordance with ethical standards governing research involving human participants. In line with institutional and national guidelines, formal ethical approval was not required because the research did not involve interventions, experimental procedures, or the collection of sensitive personal data.

Sample characteristics

The final sample consisted of 153 respondents employed in manufacturing and production-related organizations in the Republic of Serbia. With respect to gender, 139 respondents were male (90.8%) and 14 were female (9.2%), reflecting the gender structure commonly observed in manufacturing and industrial sectors. The demographic characteristics of the respondents are summarised in Table 1. The sample is predominantly male (90.8%), with most respondents holding a university degree (75.8%). The average age of respondents was 41.19 years (SD = 8.74), ranging from 20 to 66 years. Regarding educational attainment, the majority of respondents held higher education degrees. More than three quarters of the participants had completed university-level education, while a smaller proportion possessed doctoral qualifications. The remaining respondents had completed secondary or college-level education. Participants were employed across a wide range of manufacturing sectors, including food and beverage production, metal processing, automotive industry, energy and gas, chemical and pharmaceutical industries, as well as other manufacturing activities. In terms of organizational roles, the respondents represented various hierarchical levels, including top and middle management (e.g., directors, owners, and department managers), engineers and technical specialists (e.g., production, quality, and process engineers), and operational and technical staff. This diversity enhances the relevance and credibility of the collected data for analyzing sustainable manufacturing practices.

Table 1. *Demographic characteristics of respondents (N=153).*

Variable	Category	n	%
Gender	Male	139	90.8
	Female	14	9.2
Education level	Secondary school	10	6.5
	College	19	12.4
	University degree	116	75.8
	Doctoral degree	8	5.2
Age (years)	Mean (SD)	41.19 (8.74)	
	Range	20–66	

Note. Percentages may not sum to exactly 100 due to rounding

Instrument development and data analysis

Prior empirical studies on organizational performance and sustainable manufacturing provided the foundation for developing the questionnaire. It contained measurement items intended to evaluate four types of drivers: quality drivers (QM), environmental protection drivers (EPM), economic drivers (EM), and social drivers (SM). In this study, the term “drivers” is used consistently to refer to the social, economic, environmental, and quality-related factors that support sustainable manufacturing implementation. Environmental performance (ENP), social performance (SP), economic performance (EP), process performance (PP), innovation and development performance (IDP), and stakeholder performance (STP) were the six performance outcomes that were measured accordingly. A five-point Likert scale (1 = strongly disagree; 5 = strongly agree) was used to rate each item. Items were modified to represent the unique traits of Serbian manufacturing companies, ensuring clarity and contextual relevance. The appropriateness of the wording, structure, and response options for the target population was confirmed by a pilot test conducted with a small subset of respondents (n = 15). Before the full-scale survey, minor formatting and language changes were made. IBM SPSS Statistics (version 26) was used to analyze the data. To give a general picture of respondent characteristics and variable distributions, descriptive statistics were calculated. Bivariate relationships between drivers and performance metrics were investigated using Pearson’s correlation coefficients. Several multiple linear regression analyses were conducted to test the proposed relationships. Six categories of performance outcomes - environmental, social, economic, process, innovation and development, and stakeholder - were designated as dependent variables, and four categories of drivers - social, economic, environmental, and quality - were designated as predictor variables. To evaluate each driver’s distinct contribution while accounting for shared variance among predictors, separate regression models were estimated for each outcome dimension, with all drivers entered simultaneously.

Unstandardized coefficients (B), standard errors (SE), standardized coefficients (β), p-values, and R2 and adjusted R2 values were used to report the results as measures of explanatory power. Model diagnostics validated the assumptions of linearity and homoscedasticity. Multicollinearity diagnostics were examined prior to regression analyses, and variance inflation factor (VIF) values were below commonly accepted thresholds, indicating that multicollinearity did not pose a concern for the estimated models.

Results

Descriptive statistics and correlations between study variables

Descriptive statistics, reliability coefficients, and correlations between study variables are presented in Table 2. All scales demonstrated acceptable internal consistency, with Cronbach's alpha values ranging from .69 to .87. The distributions of the variables were considered acceptable for the planned parametric analyses. Skewness values were within ±2, while kurtosis values were mostly close to conventional thresholds, with several values slightly exceeding ±2. Given the sample size and the absence of extreme deviations, the variables were treated as sufficiently approximately normally distributed for correlation and regression analyses. The four types of drivers were positively and strongly correlated with each other (rs = .57–.74, ps < .001). They also showed positive associations with all performance outcomes, with correlations ranging from moderate to strong (rs = .41–.75, ps < .001). The pattern of correlations suggests that stronger sustainability drivers are consistently associated with higher performance across environmental, social, economic, process, innovation and development, and stakeholder domains. Among the performance indicators, intercorrelations were consistently strong (rs = .51–.76, ps < .001), indicating that higher levels of one type of performance were generally accompanied by higher levels of other performance dimensions.

Table 2. *Descriptive statistics, reliability coefficients, and correlations between study variables*

	1	2	3	4	5	6	7	8	9	10
1. Social drivers	1									
2. Economic drivers	0.622 **	1								
3. Environmental drivers	0.624 **	0.734 **	1							
4. Quality drivers	0.628 **	0.643 **	0.571 **	1						
5. Environmental performance	0.524 **	0.611 **	0.704 **	0.445 **	1					
6. Social performance	0.559 **	0.645 **	0.604 **	0.579 **	0.619 **	1				
7. Economic performance	0.592 **	0.633 **	0.629 **	0.586 **	0.704 **	0.701 **	1			
8. Process performance	0.557 **	0.624 **	0.660 **	0.558 **	0.655 **	0.668 **	0.746 **	1		
9. Innovation and development performance	0.474 **	0.638 **	0.665 **	0.417 **	0.751 **	0.647 **	0.764 **	0.732 **	1	
10. Stakeholder performance	0.494 **	0.552 **	0.500 **	0.528 **	0.508 **	0.630 **	0.687 **	0.701 **	0.608 **	1
Min–max	6–25	4–19	4–20	4–20	5–24	4–20	4–20	4–20	4–20	4–20
M	18.58	14.77	14.75	15.05	17.98	15.21	14.13	14.95	14.98	14.86
SD	3.36	2.79	3.29	3.01	3.99	2.94	3.19	2.79	3.34	3.08
Skewness	−0.85	−1.34	−1.27	−1.06	−1.10	−1.23	−0.82	−1.39	−1.21	−1.18
Kurtosis	0.86	2.55	1.87	1.12	0.69	1.91	0.88	3.13	1.30	2.06
α	0.69	0.71	0.74	0.75	0.79	0.76	0.76	0.74	0.87	0.81

Note: M = mean; SD = standard deviation. ** p < 0.01

Multiple regression analyses of drivers predicting performance outcomes

Results of six multiple regression analyses are presented in Table 3. Together, the four types of drivers explained between 36% and 51% of the variance in performance outcomes, with adjusted R^2 values ranging from .36 (stakeholder performance) to .51 (environmental performance). For environmental performance, environmental drivers were the strongest positive predictor (β = .53, p < .01), and economic drivers also showed a significant positive effect (β = .19, p < .05), whereas social and quality drivers were nonsignificant. In the case of social performance, three drivers, economic (β = .30, p < .01), environmental (β = .19, p < .05), and quality (β = .20, p < .05), emerged as significant positive predictors, while social drivers did not contribute significantly. For economic performance, all four drivers showed significant positive associations: social (β = .18, p < .05), economic (β = .21, p < .05), environmental (β = .25, p < .01), and quality (β = .19, p < .05). In contrast, for process performance, only environmental drivers significantly predicted outcomes (β = .36, p < .01), while the remaining predictors were nonsignificant. Regarding innovation and development performance, economic (β = .35, p < .01) and environmental drivers (β = .43, p < .01) both emerged as strong predictors, whereas social and quality drivers did not reach significance. Finally, for stakeholder performance, economic (β = .25, p < .05) and quality drivers (β = .23, p < .05) were significant positive predictors, while social and environmental drivers were nonsignificant. Taken together, the results indicate that environmental and economic drivers most consistently predicted performance across domains, with environmental drivers in particular showing the strongest effects for environmental and innovation and development outcomes.

Table 3. *Multiple regression analyses predicting performance outcomes from sustainability drivers*

Performance

	Environmental		Social		Economic		Process		IDP		Stakeholder	
Drivers	B (SE)	β	B (SE)	β	B (SE)	β	B (SE)	β	B (SE)	β	B (SE)	β
Social	0.13 (0.09)	0.11	0.12 (0.07)	0.13	0.18 (0.08)	0.18 *	0.10 (0.07)	0.16	0.04 (0.08)	0.04	0.12 (0.08)	0.13
Economic	0.27 (0.13)	0.19 *	0.31 (0.10)	0.30 **	0.24 (0.11)	0.21 *	0.18 (0.09)	0.18	0.42 (0.11)	0.35 **	0.27 (0.12)	0.25 *
Environmental	0.64 (0.11)	0.53 **	0.17 (0.08)	0.19 *	0.24 (0.09)	0.25 **	0.31 (0.08)	0.36 **	0.44 (0.09)	0.43 **	0.10 (0.09)	0.11
Quality	−0.06 (0.11)	−0.04	0.19 (0.08)	0.20*	0.21 (0.09)	0.19 *	0.15 (0.08)	0.16	0.08 (0.09)	0.08	0.23 (0.09)	0.23 *
R^2	0.521		0.494		0.512		0.507		0.494		0.374	
adj. R^2	0.508		0.480		0.499		0.494		0.480		0.357	

Note. B = unstandardized regression coefficient (standard errors in parentheses); β = standardized regression coefficient; R2 = coefficient of determination; adj. R2 = adjusted R2. * p < 0.05; ** p < 0.01

Discussion

The study's findings offer new empirical insights into how social, economic, environmental, and quality drivers impact long-term organizational performance in Serbia's manufacturing industry. The results indicate that social drivers have a moderate but positive influence, while quality drivers exhibit mixed effects. In contrast, economic and environmental drivers have the most substantial impact on performance outcomes, aligning with global research trends. The significant influence of economic drivers underscores the ongoing importance of cost optimization, efficiency, and innovation in fostering sustainable manufacturing. Technologies such as automation, artificial intelligence, and predictive maintenance can increase productivity while reducing waste production and operating expenses (Polese et al., 2021; Mahfoud et al., 2024; Agrawal et al., 2023). In addition to increasing production efficiency, these technological advancements make organizational systems more robust and flexible. Additionally, one of the main factors facilitating sustainable industrial transformation is technological and economic preparedness (Narkhede et al., 2025; Renna and Materi, 2021). Environmental factors are also important, as evidenced by the increased consciousness of ecological responsibility in contemporary manufacturing. The importance of environmental considerations in this study aligns with earlier research that emphasizes energy efficiency, the circular economy, and green innovation as crucial components of sustainable operations (Rosen and Kishawy, 2012; Panagiotopoulou et al., 2022; Shaikh et al., 2024). This research indicates that manufacturing companies in transition economies, such as Serbia, are starting to recognize environmental performance as both a source of competitive advantage and a compliance requirement. Furthermore, it has been demonstrated that combining environmental management systems with green product design improves an organization's long-term resilience and reputation (Bravo et al., 2022; Ghazali et al., 2023). Employee engagement, safety, and corporate social responsibility are valued, but they are still evolving as strategic pillars in the region's manufacturing culture, influenced by moderate social drivers. From a cognitive-organizational perspective, the findings suggest that sustainability performance is not driven exclusively by technological readiness or financial investment, but also by the extent to which employees internalize sustainability principles. Workforce training, participatory decision-making, and organizational learning mechanisms contribute to the translation of sustainability strategies into operational practices. This reinforces the view that sustainable manufacturing transformation requires alignment between technological systems and human cognitive capacities (Norton et al., 2015). This partially supports earlier research, which shows that when social initiatives - such as training, well-being, and stakeholder involvement - are fully incorporated into management practices, they improve performance focused on sustainability (Madero-Gómez et al., 2023; Baykal and Divrik, 2023; Lee, 2018). The statistically minor impact, compared to economic and environmental drivers, however, may be the result of organizational priorities that prioritize operational and financial stability over more extensive social change, in the context of developing or transition economies such as Serbia. Challenges such as limited financial resources, regulatory gaps, and lower awareness present significant barriers to adoption. For example, studies on the long-term growth of the Serbian manufacturing sector highlight the need for innovative industrial policy, structural limitations, and a lack of specialization in high-value goods (Mićić and Savić, 2018). Additionally, sustainability advancement has been linked to Serbia's readiness for digital transformation, indicating that technological capabilities may serve as a facilitator of sustainable practices in manufacturing organizations (Rakic et al., 2021). Understanding what drives businesses to adopt sustainable manufacturing practices is crucial in light of these opportunities and challenges. The findings collectively demonstrate that a balanced set of drivers is necessary for sustainable performance in manufacturing organizations. While social and quality dimensions enhance organizational adaptability and long-term resilience, economic and environmental factors offer the structural underpinnings for sustainable transformation. Understanding these driver mechanisms is particularly crucial for guiding managerial strategy and industrial policy in transition economies like Serbia, where businesses frequently face financial constraints, technological gaps, and evolving regulatory environments. Adopting green technologies or efficiency improvements alone will not be enough to achieve sustainability in manufacturing; human-centric innovation, environmental responsibility, and economic rationality must all be integrated systemically. Sustainable manufacturing can be accelerated by implementing circular economy practices, and enhancing digital transformation readiness, according to emerging research (Lim et al., 2023; Dacre, 2024). This is especially true in developing nations where workforce engagement and resource optimization continue to be significant obstacles. To achieve synergistic effects on sustainability outcomes, recent studies emphasize the importance of multi-level driver frameworks that integrate social participation, technological capability, and quality management (Scharmer et al., 2024; Hariyani et al., 2023; Abubakr et al., 2020; Gholami et al., 2021). Future studies should, therefore, examine how organizational culture, digital technologies, and policy tools interact to strengthen these forces and bridge current implementation gaps. This kind of data can help the transition economies develop targeted programmes that enhance competitiveness, foster innovation, and ensure alignment with international sustainability goals. Although the sample included respondents from diverse manufacturing sectors, future studies could further examine sector-specific differences in sustainability drivers and performance relationships.

Conclusions

This research examined how quality, social, economic, and environmental drivers influence long-term organizational performance in Serbian manufacturing firms. The findings underscore the importance of creativity, effectiveness, and ecological responsibility in promoting sustainability, demonstrating that both economic and environmental factors have a significant positive impact. By emphasizing the growing importance of employee engagement, safety, and well-being in creating resilient organizations, social drivers also play a significant role. Quality drivers, on the other hand, exhibit conflicting results, indicating that their role in sustainability is still developing in this regard. Overall, the results highlight the need for a well-rounded strategy that balances economic and environmental priorities with more robust social and quality-oriented practices. In addition to investing in people, organizational culture, and systems for continuous improvement, managers should concentrate on increasing technological innovation and resource efficiency. Despite offering insightful empirical data from a transition economy, this study remains limited to a single country and sector. Future studies should investigate the interactions between these drivers over time and across different geographical and industrial contexts. A deeper understanding of the dynamic mechanisms underlying sustainability in global manufacturing systems may be possible through comparative, longitudinal, and multi-level analyses.

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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

All ethical considerations were observed, including the confidentiality of personal information, voluntary participation, and data protection in accordance with applicable legal and institutional guidelines.

Author Contributions

Conceptualization, S.Vasić; methodology, S.Vasić; software, S.Vasić. and K.R.; validation, S.Vasić and N.B.; formal analysis, S.Vasić; investigation, S.Vasić and N.B.; resources, S.Vulanović and N.B.; data curation, S.Vasić., K.R., D.V. and N.B.; writing-original draft preparation, S.Vasić; writing-review and editing, S.Vasić.; visualization, S.Vulanović; supervision, N.B.; project administration, S.Vasić and K.R.; funding acquisition, S.Vasić, K.R., N.B., and D.V.;

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Development of a Cloud-Based WebRTC VoIP Application Using the Docker Platform for an Educational Environment

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Abstract: The development of real-time communication systems has become increasingly important for educational institutions seeking flexible, scalable, and cost-effective digital learning environments. This paper presents the design, implementation, and performance evaluation of a cloud-based WebRTC Voice over IP application deployed through Docker container technology and integrated into an educational e-learning system. The proposed solution enables secure browser-based audio and video communication between instructors and students, as well as among students, without requiring additional plugins or native software installation. The application architecture is based on multiple containerized microservices, including database, WebSocket, Apache, and Nginx components, hosted within the Microsoft Azure cloud environment. To assess the efficiency of the proposed model, performance testing was conducted across three deployment infrastructures: bare-metal server, virtual server, and Docker-based platform. The evaluation included application deployment time, startup time, system restart time, and response time under different numbers of concurrent sessions. The results indicate that the Docker-based implementation achieved the best overall performance, with substantially shorter deployment and startup times and lower response latency compared with both bare-metal and virtualized alternatives. These findings confirm that containerized WebRTC infrastructure can improve scalability, maintainability, and responsiveness in educational communication systems. The study contributes a practical implementation model for integrating real-time VoIP and video communication into e-learning platforms, particularly for institutions seeking open-source, cloud-ready, and resource-efficient communication solutions.

Keywords: *Docker, Container, WebRTC, Educational Institution Software, Voice over IP.*

Introduction

The accelerated development of technology has enabled us to eliminate expensive international calls by using alternative solutions to telephony. Now we have Voice over IP (VoIP) applications that represent telephone calls over the Internet. During the COVID-19 pandemic, the use of VoIP applications was at its highest level. These applications were used for various purposes, such as school lectures, business meetings, remote work, and more. The constant development of technology and the popularization of Internet usage among the masses, for both business and personal purposes, contribute to the expansion of VoIP. Additionally, there is a growing need for multimedia services and communications.

However, VoIP communication still occupies only a small portion of communications today. The future of VoIP lies in the capabilities of the new and more advanced applications, where voice is just one piece of information. VoIP applications are usually designed as client-server applications, such as Microsoft Teams or Google Meet. These commercial versions are hosted in the cloud, physical, or virtual

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servers within a local infrastructure. Due to a large number of dependencies that these applications use, their actual startup takes a long time.

The aim of this research project was to build a VoIP application based on the WebRTC (Web Real-Time Communication) protocol, which will connect people in real-time.

Application code is provided for free, so it may be built upon and possibly integrated with other applications. Since WebRTC is a client-server technology usually installed on physical and virtual servers, we wanted to go with Docker as an underlying platform for our application (Hartono et al., 2025).

The expectation was that it would perform better than certain traditional implementations, such as bare-metal and virtual installations. The application design uses multiple software containers (microservices), thereby optimizing the application performance, startup time, as well as improving the quality of maintenance procedures.

After creating the application, we performed the necessary measurements, and compared the speed and performance of our implementation with the mentioned traditional ones. During the implementation, Docker was used with an initial setup on the Windows 11 operating system, where all the containers were deployed. After the successful implementation of the development platform, the containers were migrated to Microsoft Azure cloud to serve as the basis for the production platform.

In the following chapters, the essential concepts and features of Docker are explained, along with the differences among the traditional infrastructures (i.e., virtual and physical servers). This serves as the theoretical background for demonstrating the technologies behind our WebRTC-based application (Castro-Castaño et al., 2026). This application allows us to reach a significant performance increase for VoIP applications, as evident by its implementation on the Docker platform.

Related work

Since data is one of the most valuable assets of the modern world, it is highly important to protect it. Once transmitted over the public network, audio and video data become vulnerable to cyberattacks. In their research paper, Chithra and Aparna have proposed an innovative method (a blockchain-enabled dual level security scheme) of transmitting video data over a secret channel, thereby adding a security aspect to the transmission of audio/video data (Chithra and Aparna, 2023).

The importance of their novel solution for this work lies in the security hardening of our web application for VoIP calls, based on the open-source WebRTC technology.

Although the experimental analysis conducted by Chithra and Aparna was mainly focused on video data, the proposed solution can potentially be applied to voice data as well. This is one type of data processed by our WebRTC-based application, and the possibility for future enhancements lies in the application of the mentioned security scheme on that data.

Since the research project represented in this paper brings novelty and is open for further development, it is relatively difficult to find a similar solution, especially with the Docker platform in use.

Docker software

Docker is software that is supported on both Linux and Windows operating systems. It is a tool designed for creating, deploying, and running applications using containers. Its use is of greatest benefit for developers who can choose their preferred platform and develop on it without worrying about the operating system on which their application is going to run. Docker offers manageable virtual environments called containers. A single Docker instance can have multiple containers, each operating independently and in isolation from one another.

Considering that Docker uses virtualization to create containers, the concept strongly resembles a virtual machine. Although both approaches provide isolated runtime environments, there are significant differences in how they operate. The obvious difference is that Docker consumes fewer resources, is faster, and lightweight on the system (Docker, 2024). The advantages of this model are manifold, but the most significant benefit is application compatibility. In practice, this means that an application developed within a container will function seamlessly on any Docker, regardless of compatibility issues. Packaged within such an isolated environment (container), the application is easier to develop, maintain, and use.

The main Docker components are: Docker platform, Docker engine, Docker architecture (Docker client, Docker daemon, Docker registry), Docker objects (images, containers, services), and Docker Hub.

Docker platform

The Docker platform is a set of tools that enable us to manage the lifecycle of containers. This platform was chosen because it allows for creation, management, and maintenance of applications in microservices that are packaged in software containers. The containers are isolated from each other. They contain their own software, libraries, and configuration files. They communicate with each other via precisely defined channels. Docker is essentially an approach to virtualization where the setup is less complex. For the Docker platform to work, there needs to be a basic operating system and software on the server that enables the use of containers – Docker Engine. On the other hand, for virtualization platforms, an appropriate hypervisor is required, and each individual virtual machine must have its own operating system installed on which the desired application runs (Lv et al., 2026). Virtual machines are therefore more flexible because they do not depend on the underlying host operating system. But software containers are significantly less complex and more efficient in resource utilization, allowing for 4 to 6 times more containers to run on the same server than virtual machines. All containers are managed by the operating system kernel and are therefore lighter than virtual machines.

Docker engine

The Docker Engine is a client-server application with the following components:

- Server, which is a long-running process called a daemon. This process runs in the background and responds to requests sent to it.
- REST (Representational State Transfer) API (Application Programming Interface), which specifies interfaces that programs use to communicate with the daemon and send it instructions.
- CLI (Command Line Interface).

The command-line interface uses the Docker REST API to control and communicate with the Docker daemon through scripts or direct CLI commands. The daemon creates and manages Docker objects such as containers, networks, and disks. Figure 1 illustrates how Docker components are interconnected.

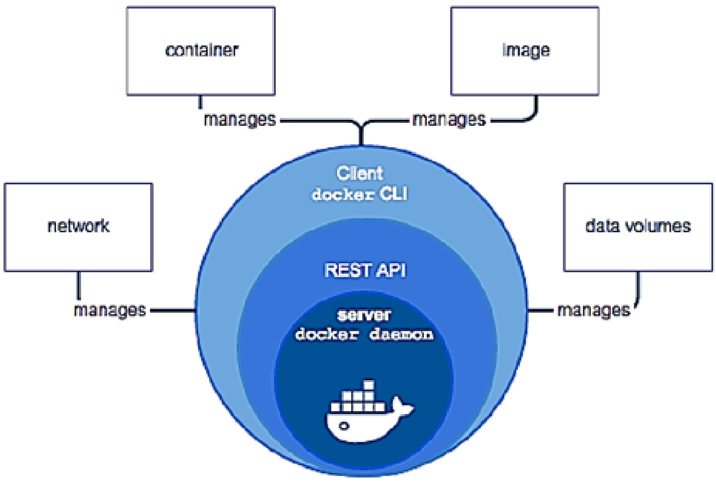

Figure 1. Components of Docker Engine (Docker, 2024)

Docker architecture

The Docker architecture is based on the client-server model and defines the operation and relationships of the basic Docker components. In Figure 2, the connections between individual components in the client-server architecture are shown. The client and daemon may or may not be on the same server; as needed, the client can be connected to the daemon remotely.

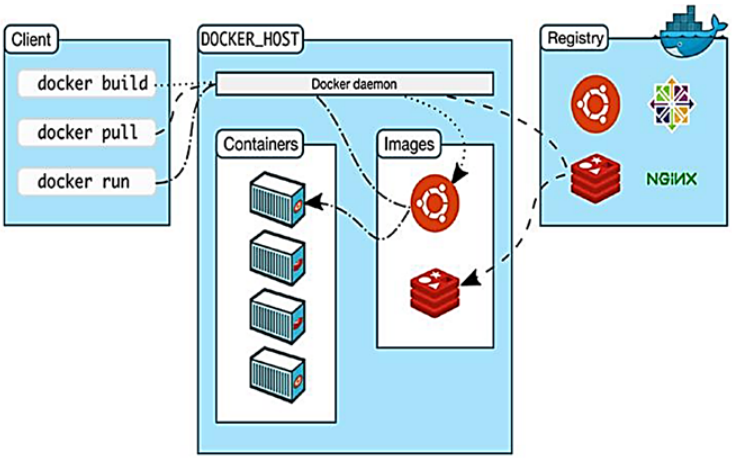

Figure 2. Docker architecture (Kumar, 2024)

The Docker client is the primary means of user interaction with Docker. Using commands via the command-line interface, the client forwards them to the Docker daemon over an API. The daemon is a server process that runs continuously in the background, monitors the REST API for incoming command processing requests, and executes them. Software images for Docker must be stored at a specific loction for easy access. This location is called the Docker registry. Docker Hub is an example of a public registry that anyone can use, and Docker is configured by default to use Docker Hub. However, users can use their private registry as needed.

Docker objects

Objects include images, containers, services, and volumes. Objects are primarily generated by the Docker daemon. On the other hand, images are read-only system files containing instructions for creating a container that can run an application. A Dockerfile contains simple commands executed by the daemon to create and run images. Each command in the Dockerfile creates a separate layer within the image.

When we modify the Docker file to change the image, only those layers containing the change are affected. This is the main reason why images consume much fewer resources than virtual machines.

When we talk about containers in the context of applications and software, we can compare them to the real shipping containers. Before being standardized, shipping goods was a demanding and costly process. Depending on the type of goods and the shipping method used, it was necessary to adjust the packaging method. Standardizing containers balanced the way goods are shipped, regardless of type, shape, size, and mode of transport. The amount of work was reduced with the simplification of the process, leading to significant time and cost savings (Jangla, 2018).

A similar principle applies to software containers. We have an image that is run inside the container, and the container only includes what is necessary to run the application. We can then transport and run this container anywhere. Instead of installing the entire operating system and all the accompanying software, the container typically contains only the following components: the application itself, necessary libraries, components on which the application depends (dependencies), as well as configuration files and folders (shown in Figure 3). The application thus becomes independent of the type of operating system distribution and infrastructure on which it is run.

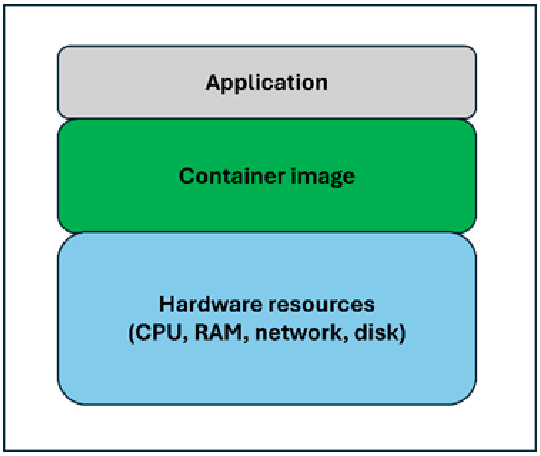

Figure 3. Architecture of a container

Containers are often associated with, or even confused with, the concept of virtual machines. Virtal machines run within a virtualization software and actually represent separate operating systems within the host. Therefore, they have their own libraries and programs, but also occupy several gigabytes of memory space (Shih et al, 2021). On the other hand, containers are essentially just isolated environments within the host operating system and they contain their own libraries for specific processes and applications, making them much smaller when stored in memory (Kul et al, 2024). Below in Figure 4 is a diagram illustrating the technical differences between virtual machines and containers (Jones, 2018).

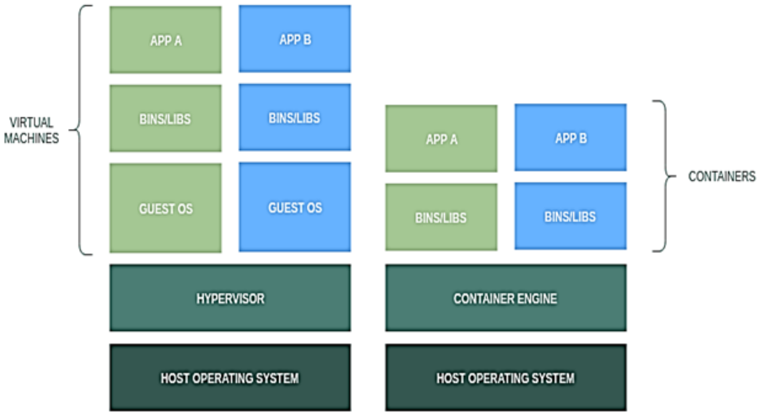

Figure 4. Containers vs. virtual machines

Services allow users to scale containers across multiple Docker instances. In this way, multiple containers can work together via the Docker API and exchange data among themselves to perform a task. To the end-user, it will appear as if all the work is being done by a single application.

Docker Hub

Docker Hub is the primary location for hosting Docker Images. It is a cloud-based public registry on which images can be stored and from which they can be pulled. It serves as a centralized distribution and discovery point for images. Users can buy or sell images on Docker Hub, or distribute them for free. Images can be searched using either the Docker Hub interface or the CLI.

WebRTC web application

WebRTC is a free open-source project that provides web browsers and mobile applications with real-time communication via the application programming interface (API). It enables audio and video communication within web pages, allowing direct peer-to-peer communication, and eliminating the need for installing plugins or downloading native applications (WebRTC Code Samples, n.d.).

The project is a web-based application that enables the establishment of video calls using WebRTC open-source code. Architecturally, the web application is implemented using containers hosted on Microsoft Azure. As part of the application, a user registration and login portal has also been developed, enhancing the application's security. The application code is freely available to all interested parties. The goal of developing such an application is to contribute to the community by allowing users to reduce their communication costs without investing in the development of similar applications. It will primarily help smaller companies and businesses that do not have enough resources or manpower to spend time on developing the application. The developed WebRTC platform can be integrated into any application that has a developed API interface. Architecture of the WebRTC application is shown in Figure 5.

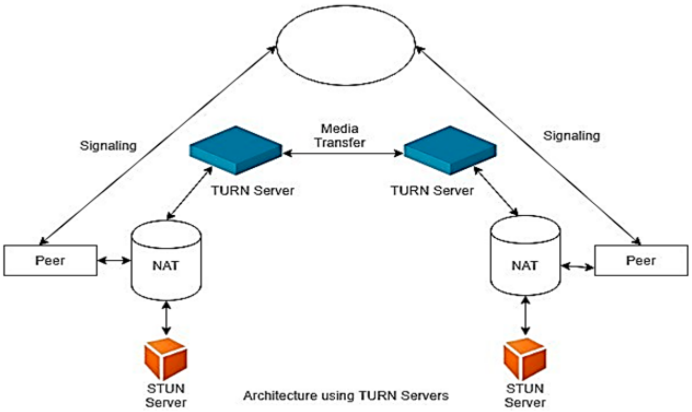

Figure 5. Architecture of the WebRTC application (The Past, Present, and Future of WebRTC, 2022.)

WebRTC is an open-source project that enables real-time audio, video, and data communication via web and native applications. In our project, we have utilized a portion of WebRTC for voice communication.

WebRTC has several JavaScript APIs, out of which the most popular ones are:

- getUserMedia: enabling the use of input functions (camera and microphone);
- MediaRecorder: audio and video recording;
- RTCPeerConnection: audio and video streaming between users;
- RTCDataChannel: data streaming between users.

For a WebRTC web application to work properly, we need a signaling service, commonly referred to as signaling or „signaling server" (Signaling and Video Calling - Web APIs | MDN, 2024.). WebRTC uses RTCPeerConnection for streaming data communication between browsers, but a mechanism for coordinating communication and sending control messages is also required. WebRTC does not specify signaling methods and protocols. As part of this project, we can use Socket.IO for message exchange, but there are other alternatives. For a WebRTC application to establish a call, its clients must exchange the following information: session control messages for opening or closing communications, error messages, media metadata (codecs, codec settings, bandwidth, and media types), key data for establishing secure connections, and network data (i.e., host's IP address and port as seen by the external side of the network) (Almousa et al, 2021).

The signaling process requires a mechanism for clients to exchange messages back and forth. This mechanism is not implemented by the WebRTC API itself but must be created independently. WebRTC is designed to operate on a peer-to-peer connection basis, allowing users to connect in the most direct way possible. However, WebRTC is built to support the latest networking technologies, meaning that client applications can traverse NAT gateways and firewalls if peer-to-peer call establishment fails. Call encryption is mandatory for all WebRTC components, and its JavaScript APIs can only be used in secure communication via Hypertext Transfer Protocol Secure (HTTPS) connection.

Application design

The following image (Figure 6) shows a schematic representation of Docker containers on a local computer and the Microsoft Azure platform.

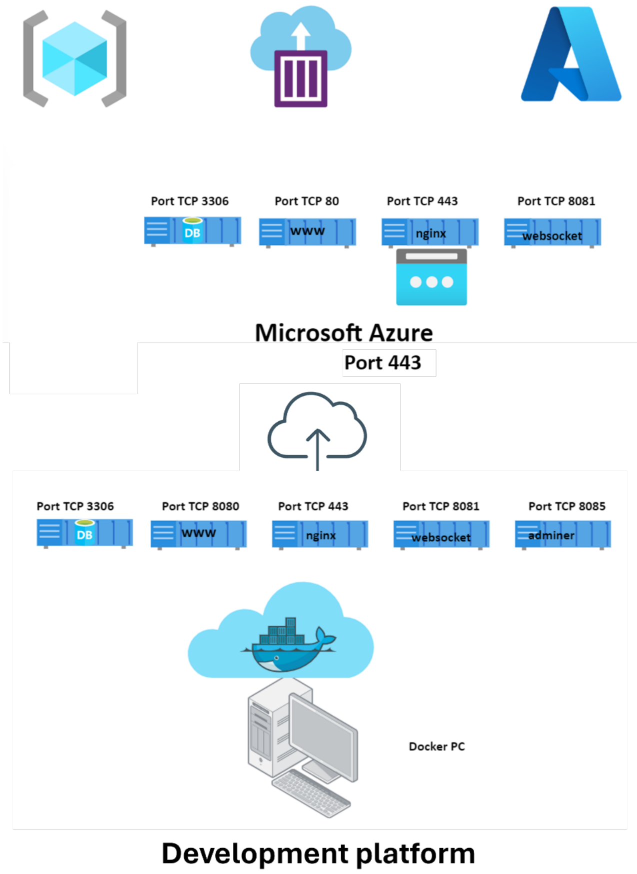

Figure 6. Design of the WebRTC application

WebRTC application is completely free and can be downloaded with the accompanying code on GitHub (Alenkamis, 2022.). The application on Microsoft Azure consists of four containers ("DB", "Websocket", "Nginx", and "www"), and one Linux virtual machine.

The DB container is a part of the web application where a MySQL database, necessary for the website, is located. Within the DB container, a database named "web" has been created. Inside the "web" database, there is a table called "users", where users who register on the web application are stored. The websocket container is a part of the web application that provides support for working with websockets, since the PHP programming language does not natively support the WebRTC platform. Due to excellent native support for websockets, Node.js was used for the message exchange microservice between components, thereby avoiding undesired effects. The configuration for websockets in Node.js consists of the server-side and client-side parts. The server-side configuration is located in the "websocket" container, while the client-side configuration is located in the "www" container. The www container is crucial for the web application because it contains the Apache server. From the Docker configuration files, it can be concluded that the website is located in the /var/www/html folder. The following files, necessary for the operation of the web application, are located inside the html directory: **call.php**, **functions.php**, **index.php**, **login.php**, **logout.php**, **registration.php**, **script.js**, and **socket.io.js**. The Nginx container serves as the frontend web server that users first encounter when accessing the WebRTC application. Upon connection attempt, users connect to the Ngnix Web server via TCP port 443, which is a standard for HTTPS sessions. A Let's Encrypt certificate is implemented directly on the container to prevent users from encountering errors when opening the application (Ardi et al, 2025).

The following image (Figure 7) depicts the entire operation of the WebRTC application, from accessing the website to establishing a VoIP call to another user.

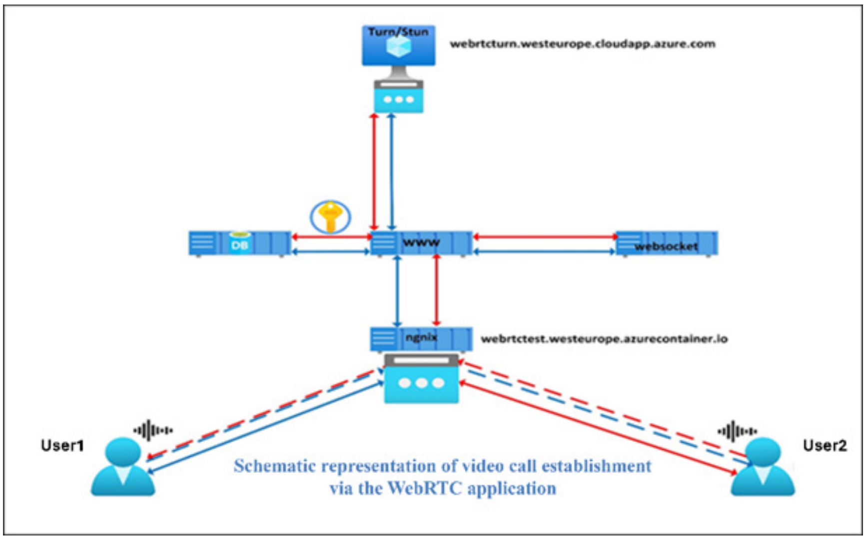

Figure 7. Schematic representation of video call establishment via the WebRTC application

Results of WebRTC application performance testing

The development of the WebRTC platform on Docker infrastructure has opened the possibility of measuring and testing performance across three different systems. The first system is a developed platform based on bare-metal infrastructure (Ubuntu Server 22.04 version), the second platform is a virtual server (Ubuntu Server 22.04 version), and the third is the WebRTC platform on Docker infrastructure.

All measurements were conducted on the same server with identical specifications: Dell PowerEdge R660, Intel Gold 6139 processor, 256 GB RAM, 4 x 1.92 TB SSD disks, and 2 x 10G network adapters. Performance measurements were carried out using iPerf and nPerf software tools, which provide the necessary capabilities.

iPerf is a powerful tool that allows the testing of network throughput, latency, and packet loss within a mesh network. iPerf enables the generation of network load to assess the maximum data transfer speed and identify potential network bottlenecks (Garcia et al, 2017). This tool provides detailed reports and measurement results, allowing us to identify and resolve issues in the application's operation (Yadav et al, 2018).

nPerf is a tool that also tests data transfer speed and latency within the application to gain insight into its performance. nPerf provides detailed results that help analyze connection quality and identify potential problems. Whether in the implementation, maintenance, or optimization phase of the application, nPerf can help in the better understanding of its performance and quality improvement (Marinković et al, 2021).

The research and WebRTC application testing results are presented in the following table (Table 1). It provides insight into application performance after each type of test given in the table is applied across three different platforms.

Table 1. *Results of WebRTC application performance testing on three different platforms*

Type of test	Bare-metal WebRTC	Virtual server WebRTC	Docker platform WebRTC
Initial application deployment (minutes)	120	35	6
Application startup (seconds)	106	41,2	7
System restart (seconds)	120	50	11
Application response without any calls (milliseconds)	89,3	67,1	17,6
Application response with 5 concurrent sessions (milliseconds)	102,4	77,5	21,2
Application response with 10 concurrent sessions (milliseconds)	124,2	88,9	24,7

The following graph (Figure 8) shows the loads in application response during a specific number of calls, with the values expressed in milliseconds.

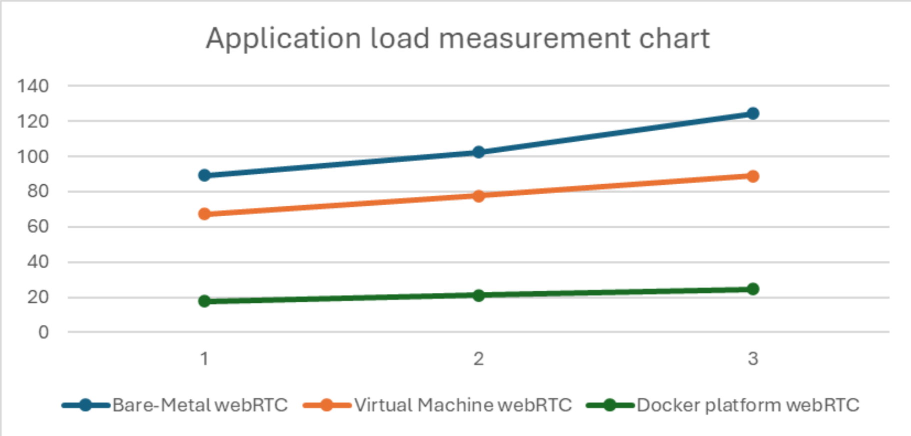

Figure 8. Application load measurement chart

Using Laplace's matrix and Hertz's formulas for loads (without startup and deployment data), we arrive at the application performance results showing that the bare-metal platform (physical) is convincingly the slowest, while the virtual machine platform is 24.8% faster than it. However, ultimately, it can be said that the Docker platform is the fastest in the test and has the best performance, being 81.3% faster than the bare-metal platform and 72.3% faster than the virtual one.

WebRTC Integration within the E-Learning System

The developed WebRTC application has been successfully integrated into our existing e-learning system, enabling secure, real-time communication between instructors and students. The application uses Web Real-Time Communication WebRTC technology, which allows direct peer-to-peer exchange of audio and video data within a web browser, without the need for additional plugins or software. This approach enables instructors to communicate with students in real time, as well as interact with each other, significantly enhancing the interactivity of lessons and supporting dynamic educational processes. Furthermore, students can communicate among themselves, which further promotes collaboration, teamwork, and the collegial exchange of knowledge.

In the professional literature, WebRTC is increasingly recognized as a superior technology for real-time communication compared to traditional infrastructures based on virtualization or physical servers, due to its peer-to-peer architecture and low latency. Peer-to-peer communication allows direct data exchange between end users, significantly reducing the load on central servers and infrastructure, which contributes to faster and more efficient media transmission (Mahmoud and Abozariba, 2024).This approach does not require complex virtualized or physical server infrastructures, minimizing latency and improving user experience, particularly in real-time scenarios such as video calls and interactive discussions.

Because of these advantages, WebRTC is increasingly used in modern educational platforms and communication systems, as it combines low latency, scalability, and efficient use of network resources without the need for large server farms or complex virtualized environments (Mahmoud and Abozariba, 2024). In our case, the platform is already integrated into the e-learning system and enables immediate and smooth interaction between instructors and students, as well as among students themselves, significantly improving the quality of the learning process and supporting reliable real-time communication.

Conclusions

The work briefly describes the mechanisms of Docker infrastructure and explores the operation of the created WebRTC-based application for VoIP and video communications. WebRTC is an open-source platform, and as such, it is very interesting for use. The goal of developing this application is to contribute to the community by enabling users to reduce their communication costs, without investing in the development or purchase of similar applications. Primarily, it will assist smaller companies that lack sufficient resources and manpower needed for their development.

The infrastructure of the application is built on the Docker container platform. This platform emerged in 2013 and immediately became a popular choice for development environments. Docker as a platform is increasingly being used for production systems due to the convenience of microservices. It has its advantages in terms of: a quick application startup, segmentation features that make it less susceptible to attacks, and the facilitation of simplified repairs and servicing. After testing the performance of the proposed WebRTC-based application with varying degrees of network load and using different types of tests, we have obtained the results in favor of the Docker platform implementation. It has by far shown the best performance under any type of test, whether it be the time needed to deploy the application, or its response to an increasing number of concurrent sessions (calls).

In conclusion, it is expected that the Docker container platform will continue to progress and grow in the future, and that in the coming years many applications will be based on this platform. We sincerely hope that our diligent work on this highly performant VoIP application will reach end users who will gladly use it in the future.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

The data supporting the reported results in this study are contained within the article itself.

Institutional Review Board Statement

Not applicable.

Author Contributions

Conceptualization, A.K., A.Z. and B.I.; methodology, A.K. and M.B; software, AK, B.I. and A.Z.; formal analysis, A.K., G.P. and L.C.J.; writing—original draft preparation, A.K., M.B. and A.Z.; writing—review and editing, A.K, and L.C.J. All authors have read and agreed to the published version of the manuscript.

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Misconceptions of Primary School Students about Light Phenomena

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Abstract: Primary school students are often confused when they need to explain light phenomena, and there are several factors that influence this. The purpose of the research was to determine primary school student's achievement, differences between subpopulations and the level of presence of wrong beliefs (misconceptions) about light phenomena. The sample was composed of 306 students ages 7 to 10 of three primary schools in Sombor, Serbia. The data collection was carried out using knowledge test (Krombach's alpha coefficient α = .73) developed on previous results on basic light misconceptions such as those about light sources, rectilinear propagation of light, transparency of materials and shadows. Results have demonstrated no significant difference in success among students from different schools, while, statistically significant difference was observed when comparing the results obtained from different age groups. This research elucidated that misconceptions about light phenomena were almost identical and deeply rooted among all primary school students regardless of their age. The obtained results point out to the need for more frequent checking of student knowledge with much more sensitive and valid tests, compiling an inventory of their misconceptions and, accordingly, creating innovative teaching models, which would enable successful overcoming of misconceptions.

Keywords: *primary science education, concept development, misconceptions, light phenomena.*

Introduction

The contents of sciences are difficult to learn for a significant number of students. The most common explanations for these difficulties are that scientific terms are abstract, some of them are completely unknown to students, contain a large number of variables, and that terms used in everyday life have a different meaning when used in science (Smolleck and Hershberger, 2011). Moreover, there is a gap between the requirements of scientific disciplines and the cognitive abilities of students (Milanović Nahod, S., Šaranović Božanović, N., and Šišović, D., 2003). When it comes to light, primary school students have a large number of wrong beliefs, not only about its nature, but also about the shadow formation, its size, position and shape, reflection and refraction, rectilinear propagation, etc. (Phoojaruenchanachai, S., Sumriddetchkajorn, S., and Chanhorm, S., 2009; Uzun, S., Nedim Alev, N., and Karal, I.S., 2013; Lestari, L.D., Prabowo, P, and Widodo, W., 2018; Ravanis 2018). Mental ideas about light, regardless of whether the ideas are scientifically correct or not, are the product of both individual development and influence of the environment in which the child grows up (Castro and Rodriguez, 2014). Therefore, these ideas represent the basis for upgrading, i.e. reconstruction of knowledge. In this regard, one of the science teachers' tasks is to overcome established misconceptions, and the first step towards this achievement is to discover the most common, typical and deeply rooted inaccurate beliefs of students about natural phenomena, including light.

From an early age, children perceive beings and objects from their immediate environment, and as they grow up, they develop the ability to organize stimuli, created by perception, classifying them into different classes or sequences. As the conncept represents a symbolic substitute for an important common

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characteristic of all individual cases, the development of concepts follows the development of the classification system, as well as the children's ability to apply that system to their own environment. Glynn and Duit (1995) viewed conceptions as learners' mental models of an object or an event. Concepts that arise from everyday children's experience Vygotsky named spontaneous, and their adoption is conditioned by the development of speech and language. On the other hand, during the adoption of the system of scientific knowledge in the teaching process, scientific concepts are formed and developed. The essential difference between spontaneous and scientific concepts is the lack, or existence of a system (Vygotsky, 1986). In relation to this claim, later researchers expressed two different viewpoints, that divide them in those who believe that children's previous knowledge is organized into a system named knowledge - as - theory (Carey, 1999; Chi, 2005; Ioannides and Vosniadou, 2002; Wellman and Gelman 1992), and those who consider that naive knowledge consists of hundreds and thousands of mutually independent fragments, the system named knowledge - as - element (Clark 2006; diSessa, A., Gillespie, N., and Esterly, J., 2004; Harrison, A. G., Grayson, D. J., and Treagust, D. F., 1999; Linn 2005). According to the first point of view, children enter the educational process with unique and ordered systems of naive ideas similar to theories, where changing one such idea requires changing the whole system of hierarchically superior mental models, categories or premises (Özdemir and Clark, 2007). According to the second point of view, naive knowledge consists of many mutually independent parts that represent simple generalizations of events and practical actions (diSessa, 2006) and enable the explanation and prediction of events in the immediate environment in a naive way. However, these events are not explained within a wider theoretical system. The lack of organization and fragmentation implies that naive knowledge is confused, but does not necessarily contradict scientific facts (diSessa, 1993).

The development of concepts in teaching has a central place in the research of Herbert Klausmeier, who states that concepts are the basic drivers of a child's intellectual development and that they are a key factor in the development of cognitive structures and thinking. He points out that teaching must be individualized and aligned with the students' developmental level so that they are motivated and willing to learn the concept. Knowing the name of a concept and distinguishing between defining and irrelevant attributes (properties) is essential for mastering a concept. This further facilitates classification of operations, formulating a ground rule for a group, and learning a strategy for extracting (non)examples (Klausmeier, 1985).

All concepts, i.e., everything that exists, can be classified into three primary ontological categories (branches of ontological tree): mental states, entities, and processes. Each of these categories is defined by a certain set of attributes specific only to that category (Chi, 2008). Ontological attributes represent properties that concepts can potentially possess and thus define the meaning of a given concept. Difficulties in learning concepts in class arise when students intuitively assign a concept to the wrong ontological category in relation to the one the scientific concept belongs to (Chi, M., T., H. Slotta, D., and Leeuw, N., 1994). For example, the misconception that "the cold from the ice flows into the water and therefore the water becomes colder" indicates the assumption that the ice possesses some "cold substance", such as a multitude of small cold molecules that pour into the water and settle. This means that the notions of cold or heat are perceived as belonging to the category of entities rather than processes. Change is possible only if students accept that heat or cold do not have content, color or volume, which are definitive attributes of an entity, but occur over time and thus "move up the process category". Whether students understand heat as an entity or not, most recognize that heat transfer is a process because they have experienced the obvious movement of "heat" from one place/object to another, for example, from a warm cup to cold hands. Misconceptions in the higher branches of the ontological trees of heterogeneous concepts, such as those that a platypus is a bird because it lays eggs, or that a whale is a fish because it lives in water and has fins, are easier to overcome because they do not have to "move from one category to another", but everything takes place within the primary category – entity (Chi, 2013, 60-64).

If the spontaneous view of scientific concepts has not disappeared, i.e., it has not been discovered and corrected, it can coexist with what "the teacher said", used as needed (privately or publicly - answering, testing) thus creating further confusion (Bruce and Kopnicek, 1990). One of the ways of correcting children's misconceptions is teaching aimed at conceptual change. The term conceptual change is used for learning in which students' spontaneous conceptual structures are fundamentally restructured to enable understanding of scientific concepts. The reconstruction of existing knowledge in teaching occurs by creating situations in which the student is dissatisfied with existing (spontaneous) concepts. Some researchers indicate that conceptual change is a gradual and evolutionary, not a sudden and revolutionary process (Taylor and Kovalski, 2004). This means that the change must be implemented through different activities, over a longer period of time, and with a continuous check of adoption through the new learning situations and context.

Light is a natural phenomenon that, in addition to wave properties, also has particle properties, which is a general property of matter (Vučić and Ivanović, 1989, 504). In the classroom teaching, light, as a complex scientific concept, is taught approximately as a special type of wave visible to the human eye (Radojević, 2016, 37). The focus in classroom teaching is based on the idea of the necessity of light for the life of humans and other living beings (Uzun et al. 2013), and accordingly, light is described as a form of Sun (stars) energy or energy derived from some other artificial sources (Sokanović, Lj., Lukić., G., and G. Subakov Simić, G.. 2021, 38; Kandić, A., Subakov Simić., G., Vasić., Ž., Petrović., I. and Matejić, I., 2021, 63). The contents about light are vertically connected through the first four grades of primary school and gradually become more complex, therefore, it is very important to monitor the development of those concepts, as well as, the presence of wrong beliefs at this age of students.

It has been established that many preschoolers, primary and secondary school students, and even university students interpret light phenomena in a way that is contrary to scientific laws and theories (Bendall, S., Goldberg, F., and Galili. I., 1993; Blizak 2009; Uzun et al. 2013; Ntalakoura and Ravanis 2014; Miščević, G., Blagdanić, S., and Bošnjak Stepanović, M., 2021). Through interaction with the environment, children gain experience about natural phenomena, explain them in their own way, and at the same time, oppose accepting new information that is not in accordance with their established patterns of thinking. All these contribute to the formation of children's misconceptions i.e. false beliefs (Harlen, 2010; DeVellis, 2003). Younger school-age students are often confused when they need to connect the scientific concepts they learn in school with events in their everyday experiences. The analysis of students' misconceptions about light phenomena and optical instruments revealed that daily experiences of students, the language (speech) that is used in and outside the school, teachers who, like students, have wrong beliefs, as well as inadequate textbooks, are the main factors that influence the formation of wrong beliefs (Widiyatmoko and Shimizu 2018). Among all the mentioned factors that influence children's wrong beliefs, the teachers' (mis)understanding of correct scientific facts and concepts is certainly the key. This is also confirmed by qualitative study that investigated the conceptual representations of 132 preservice Quebec elementary teachers regarding light phenomena. The conceptual difficulties identified in that study were: (1) a black-colored body absorbs all light rays; (2) light travels rectilinearly and stops when it hits a white paper; (3) a mirror reflects light; it does not absorb it; (4) the glass surface of a mirror reflect light; (5) specular reflection and diffuse reflection are confused; and (6) the shadow varies during the day because the Sun moves around the Earth (Métioui, 2023).

Research conducted with primary school students (8-9 and 11-12 years) indicated the existence of a series of misconceptions by which light is rarely correctly defined as a separate entity (Castro and Rodriguez, 2014; Grigorovitch, 2015). Namely, during the interview, the children spoke about the nature of light as something "airy" that fills the entire space and is found all around us, while, on the other hand, they claimed that light is the same as a lamp, a torch, a candle, the Sun, the Moon and the stars. Similarly, students' belief that light is only found in illuminated areas, such as a light source and an illuminated surface, failed to recognize that light is a form of energy that travels from the source, through the medium (air), to the illuminated place (Allen, 2010). Also, many children do not understand that sunlight is reflected from the surface of the Moon, but instead recognize it as a source of light (Allen, 2010; Uzun et al. 2013). One of the most embedded misconceptions about light is about the nature of vision, where the "path" of light rays is very rarely correctly depicted iconically (arrows) from the light source to the object, and then from the object to our eye. Even if a correct graphical representation is present, the explanation of the light propagation method is usually missing (Allen, 2010; Uzun et al. 2013; Ravanis, 2018).

Bearing in mind the previous findings, researchers and practitioners have implemented various teaching strategies and models (POE: Predict - Observe - Explain; Inquiry; Learning through play), trying to improve the quality and level of students' knowledge about light phenomena. The results showed that mentioned teaching approaches encouraged students' thinking activities during the acquisition of content such as the nature of light, the propagation of light, the transparency of materials, the reflection and refraction of light, which contributed to the decrease in numbers of misconceptions about light phenomena (Varela and Costa 2015; Lindstrand, A. E., Hansson, L., Olsson, R., and Ljung-Djärf, A., 2016; Lestari et al. 2018). These studies, however, revealed that complex topics are often addressed in a monodisciplinary manner despite their comprehensive nature. In contrast, a recent study presented a STEAM training proposal for future teachers, and its originality lies in the interdisciplinary approach that supports the numerous relationships and connections between the physical, chemical, biological, psychological and artistic aspects of teaching and learning about the nature of light and color. It was found that the incorporation of art and visual expression through the design and construction of an artistic-scientific object or product had a motivational effect on the learning of light phenomena, which is linked to the sensory aspects of the constructed objects (Serón Torrecilla, F. J., de Echave Sanz, A., Rodríguez Casals, C., Terrado Sieso, E. M., Pozuelo Muñoz, J., and Cascarosa Salil-las, E., 2024).

Materials and Methods

The research results on the light concepts comprehension showed that numerous preconceptions and misconceptions were present in varying degrees at all ages. Since there is an insufficient amount of research in this field, particularly among students of younger school age, this research was conducted as a contribution to the teacher practice aiming for early detection and overcoming of misconceptions about light phenomena that are complex and abstract for children. Identifying misconceptions and conducting deeper analysis can contribute to understanding how children spontaneously form mental images and how their concepts develop. Additionally, this process can highlight the need to adjust teaching methods, materials, textbooks, and curricula in order to better support their development and understanding. The importance of identifying misconceptions of elementary school students (ages 7 to 10) related to the concept of light, lies in the fact that it helps teachers to recognize and address incorrect understandings that students may have about how light works. If students are unaware of these misconceptions, they may encounter difficulties when learning more advanced scientific topics in higher grades. By identifying and clarifying these misunderstandings, teachers can provide clearer explanations and implement teaching strategies that support students in developing more accurate mental models of light. This process is vital, as it enables students to grasp fundamental physical concepts related to light and related phenomena. The aim of this research was to determine the level of misconceptions about light among primary school students, as well as to identify the most common ones.

The focus of this study was on determination and analysis of misconceptions about light among elementary school students in the lower grades. Based on a thorough review of relevant literature and previous research in science education, the authors developed and administered a test aimed at identification of specific students' misunderstandings regarding fundamental concepts and principles of light. The test was carefully designed to address key aspects of students' understanding of light and was implemented in three elementary schools.

The research was conducted in accordance with appropriate ethical principles, with all respondents being informed about the research and voluntarily accepting participation with parental consent. A total of 306 students from the 1st to the 4th grade of three primary schools in Sombor and the surrounding area participated in the research: Avram Mrazović (AM), Ivan Goran Kovačić (IGK) and Ivo Lola Ribar (ILR).

The quality and level of the students' achievements were assessed by a knowledge test on basic concepts about light: light sources, rectilinear propagation of light, transparency of materials and shadows. An overview of concepts, test requirements and cognitive levels of individual tasks is shown in Table 1.

Table 1. *Overview of concepts and requirements of the tasks in the light knowledge test*

Number	Concept	Request
1.	Light Source	Recognize and circle light sources; following illustrations were provided: a table lamp, a mirror, the Sun, an owl, a window, a flashlight, the eyes, a candle, the Moon and a neon light.
2.	Material Transparency	Recognize and circle the objects that have been made from opaque materials; following illustrations were provided: a brick wall, seawater, a glass cup, wood logs, a pencil, lenses in eyeglasses, a wooden door, window glass panes, a magnifying glass, a can, transparent document sleeve and a cup of coffee.
3.	Material Transparency	Recognize and write which objects are made of transparent, partially transparent and opaque materials; following illustrations were provided: a curtain, trousers, a magnifying glass, a transparent plastic ruler, a metal spoon, sunglasses, a book, a glass of water and a helmet visor.
4.	Natural and Artificial light Sources	Natural light sources should be circled with a green crayon, and artificial light sources with a red one; following source's illustrations were provided: the Sun, TV, a traffic light, the Moon, a fire flame, a candle flame, the stars, a chandelier, a table lamp and a lighter flame.
5.	Shadow Position	In the first part of the task, it is necessary to choose a drawing that correctly shows the position of the shadow formed behind the glass illuminated by a flashlight. In the second part of the task, it is necessary to determine the place of the flashlight and mark it with a cross, in order to create the depicted glass shadow.
6.	Shadow Size	The illustration shows a flashlight, a cardboard rectangle and a wall. In the first part of it, the flashlight is further from the cardboard, while in the second is closer to it. It is necessary to draw the size of the shadow on the wall in both cases.
7.	Rectilinear propagation of light	The five illustrations show light sources: the Sun, a street lamp, a table lamp, a candle and a flashlight. It is necessary to draw lines that show the way light propagates from the source through the air.
8.	Size and Shape of Shadow	The three illustrations show the position of the Sun at different times of the day – at 7 am, noon and 5 pm. It is necessary to draw the shadow of the tree in those periods of the day.
9.	Shape and Position of Shadow	Four illustrations show the light sources (a table lamp, a light bulb, a flashlight, and the Sun) illuminating objects of the following shapes: rectangle, arrow, circle, and square. It is necessary to draw the shadows of the mentioned objects.
10.	Size, Shape and Position of Shadow	The illustration shows a girl next to a tree whose shadow is clearly visible. It is necessary to draw the shadow of the girl, with the Sun on the right side of the drawing.

The scale for test evaluation, along with the categorization of the students' achievements, is shown in Table 2. The maximum test score was 50 points, and the students assessment time was one school period (45 minutes).

Table 2. *Test Score Scale*

Points	Success Percentage (%) and Achievement Categories
0 - 10	0 - 20 (1)
10.25 - 20	20.5 - 40 (2)
20.25 - 30	40.5 - 60 (3)
30.25 - 40	60.5 - 80 (4)
40.25 - 50	80.5 - 100 (5)

Krombach's alpha coefficient (α = .73) is considered a good indicator of internal consistency of the scale (DeVellis, 2003), especially when it comes to the knowledge tests for lower grades of primary school. Based on the recommendation of Segedinac et al. (2011), the validity of the test was assessed by an expert team with relevant qualifications, including two physics teachers, a school pedagogue and two university professors specializing in physics education. The expert team confirmed the validity of the test, noting that students from first to fourth grade were able to easily understand the items, and all tasks were clearly and precisely formulated.

Results

Data collected through the knowledge test were processed utilizing descriptive statistical tools, used for the entire sample as well as subpopulations (grade and school). To determine whether there are any significant differences in number of points achieved on the test between the subpopulations, one-factor analysis of variance (ANOVA) was performed. Additionally, the students' achievements on individual tasks were analyzed according to the answer categorization (correct, incomplete, and incorrect/no answer) and grades (I, II, III, IV).

Students' achievements on the knowledge test including the entire sample and according to the subpopulations

The distribution of students' achievements by category on the knowledge test for the entire sample is shown in Figure 1 and it was determined that it does not meet the criterion of normality.

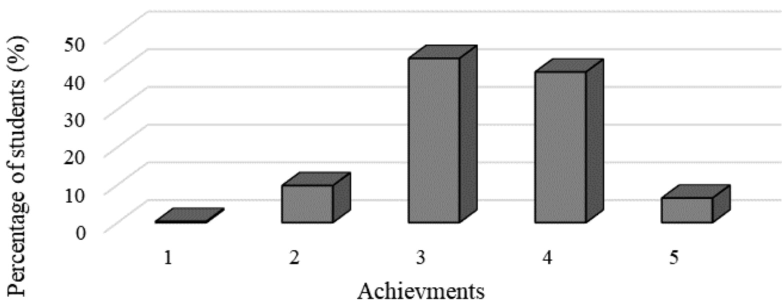

Figure 1. Distribution of students' achieements on the knowledge test for the entire sample

The average number of points achieved on the test for the entire sample was 29.53 points, (*SE* = .42), whereby the Shapiro-Wilk test determined that the condition of normality of the distribution of students' achievements was not met (p = .001 < .05). The coefficients of asymmetry (*SKEW* = -.37) and kurtosis (*KURT* = .29) indicate that the distribution curve is shifted towards the higher values, with the majority of cases within the mean of the distribution. An overview of the test results, represented via the achievements' intervals, on the entire sample and by subpopulations is shown in Table 3, where *f* is the number of students whose success on the test is in a given interval, and *p* is the corresponding percentage share in the total sample or subpopulation.

Table 3. *Overview of the test results on the entire sample and by subpopulations*

	Achievements interval		1 (0–10)pt (0-20)%		2 (10.25–20)pt (20.5-40)%		3 (20.25–30)pt (40.5-60)%		4 (30.25–40)pt (60.5-80)%		5 (40.25–50)pt (80.5-100)%	
Sample	Subpopulation	*N*	*f*	*p(%)*	f	p(%)	f	p(%)	f	p (%)	f	p(%)
Total	-	306	1	0.33	30	9.80	133	43.46	122	39.87	20	6.54
Grade	I grade	68	1	1.47	10	14.71	39	57.35	18	26.47	0	0
	II grade	68	0	0	12	17.65	31	45.59	23	33.82	2	2.94
	III grade	63	0	0	3	4.76	29	46.04	28	44.44	3	4.76
	IV grade	106	0	0	5	4.72	34	32.07	52	49.06	15	14.15
School	AM	80	0	0	5	6.25	27	33.75	43	53.75	5	6.25
	ILR	130	0	0	12	9.23	62	47.69	48	36.92	8	6.16
	IGK	95	1	1.05	13	13.68	44	46.32	30	31.58	7	7.37

Descriptive data on the accomplished number of points on the knowledge test compared between grades, indicate that students' achievements in all four grades moved towards the higher values ($SKEW_1$ = -1.06, $SKEW_2$ = -.04, $SKEW_3$ = -.08, $SKEW_4$ = -.41). However, only in the first grade the majority of cases are around the mean of the distribution ($KURT_1$ = 1.68, $KURT_2$ = -.52, $KURT_3$ = -.23, $KURT_4$ = -.16). Based on the Shapiro-Wilk test, it was found that achievements on the knowledge test meet the criterion of distribution normality for all grades except the first (p_1 = .001, p_2 = .822, p_3 = .941, p_4 = .109).

The distribution of students' achievements on the knowledge test by grades and categories is shown in Figure 2. The smallest number of points, the lowest achievement category, were accomplished only by students of the first grade, while in the second category there is a clear difference between younger (I and II grades) and older (III and IV grades) students, with percentage of younger ones being significantly higher. The percentage of students who accomplished achievements within the third category decreases, almost linearly, with the increase in grade. The linear increase in the number of students with the increase in grades is clearly visible in the two highest achievement categories, whereas the percentage of students in the highest category is significantly smaller.

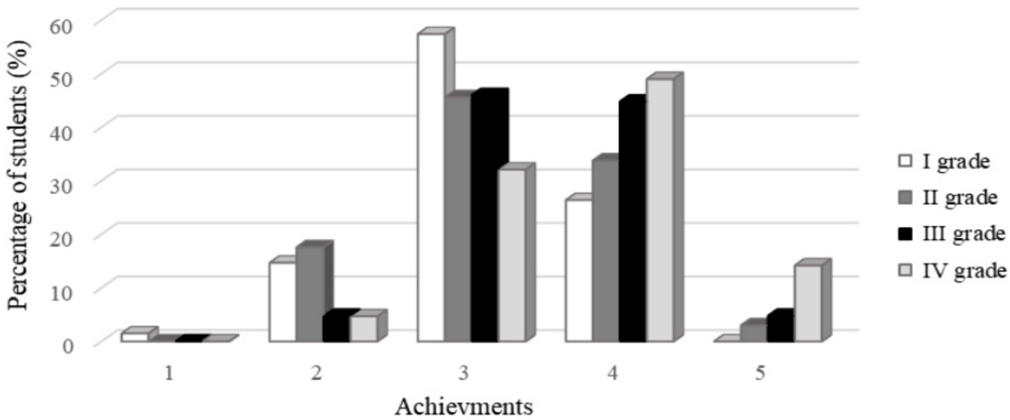

Figure 2. Distribution of students' achievements on the knowledge test according to the grade

Descriptive data on the number of points achieved on the knowledge test by school show that students' achievements in all three schools have moved towards higher values ($SKEW_{AM}$ = -.45, $SKEW_{ILR}$ = -.26, $SKEW_{IGK}$ = -.29), while only ILR school has a higher number of cases at the ends of the distribution curve ($KURT_{AM}$ = .30, $KURT_{ILR}$ = -.05, $KURT_{IGK}$ = .26). Achievements on the knowledge test meet the criterion of distribution normality for all three elementary schools (p_{AM} = .073, p_{ILR} = .387, p_{IGK} = .296).

Distribution of students' achievements by schools and categories is shown in Figure 3. Points in the lowest category of achievements were accomplished only by students in the primary school IGK. Regarding the second category of achievements, it is observed that the smallest number of students is from the primary school AM, while the largest come from IGK.

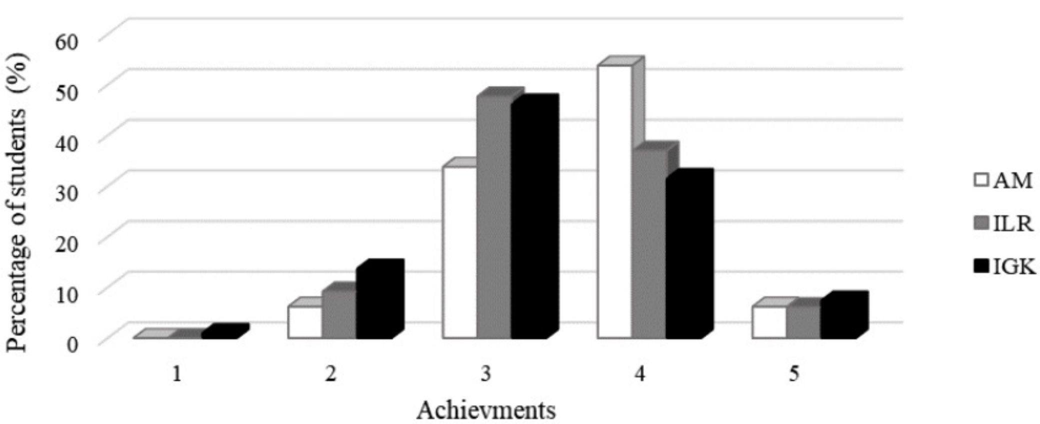

Figure 3. Distribution of students' achievements on the knowledge test by school

Students from the ILR and IGK schools achieved approximately equal and higher number of points within the third category, in comparison to those from the AM school. The percentage of students who accomplished the achievements within the fourth category is the highest in the AM school, and the lowest in the IGK school, while the highest category of achievements has approximately the same percentage of students in all three schools and is significantly lower compared to the previous two categories.

Differences between subpopulations according to the achievements on the knowledge test

One - factor analysis of variance was used to investigate the influence of grade on the number of points scored on the test. A statistically significant difference was found in the number of points achieved by different subpopulations (grades) ($F(3,302) = 17.233$, $p = .000$). Statistical significance between grades is high, as shown by the value of eta squared ($\eta p^2 = .15$), based on the guidelines given by Cohen (Cohen 1988, 284-7). Subsequent comparisons, using Tukey's HSD test, indicated that the mean score of the first grade ($M = 25.90$, $SD = 6.97$) was significantly different from those of the third ($M = 30.48$, $SD = 6.15$,) and the fourth grade ($M = 32.74$, $SD = 6.84$,) ($p = .001$ and $p = .000$ respectively). Similar trend was observed for the second grade ($M = 27.25$, $SD = 7.25$) indicating significant difference from the third and fourth grade ($p = .037$ and $p = .000$ respectively). It was established that there is no substantial difference between the first and second grade, as well as, between the third and fourth grade. One - factor analysis of variance, used to investigate the influence of the school on the number of points obtained on the test, revealed no statistically significant difference in the number of points achieved in three different schools ($F(2,303) = 1.918$, $p = .149$).

Analysis of students' answers to individual questions in the knowledge test

Figure 4 displays an overview of students' answers by categorization (correct, incomplete and incorrect/no answer) and grades (I, II, III and IV) on the knowledge test for the first five questions. It was observed that more than half of the students of all grades answered the first question correctly and that the percentage of correct answers increases with grade. Moreover, it was determined that as many as 56.54% of those who make mistake believe that the Moon is the source of light, which means that they have no knowledge that sunlight is actually reflected from the surface of the Earth's satellite. Although to a smaller extent, misconceptions were also observed about the window and the mirror as sources of light, as well as the neon light bulb, which some students did not consider as a source of light.

When it comes to the second task, it can be seen that approximately three quarters of the third and fourth grade students correctly categorized the objects based on their transparency, while the first and second grade students were less successful, perhaps due to their unconscious experience with those entities. It was shown that a certain number of students marked a transparent document sleeve (28.75%), water (18%), a magnifying glass (17.3%), a transparent glass (17%), a window (16.3%) and eyeglasses (15.3%) as non - transparent objects. In addition, a number of students marked a can (21.56%), a wooden door (21%) and a cup of coffee (19%) as transparent objects. In the third task, the introduction of the concept of partial transparency obviously led to various doubts among almost all students. Namely, this was supported by many incomplete answers, among which certainly were included some of those with only one or two incorrectly named items. The classification of light sources into natural and artificial within the fourth task, confirmed the previously observed misconception about the Moon as a light source (98%), which contributed to a huge percentage of incomplete answers in all grades (Figure 4).

Furthermore, it was observed that three quarters of students believe that fire is a natural source of light, while a significantly smaller percentage of them wrongly believe that it is also the flame of a candle, a lighter, a lamp and a traffic light. In the fifth task, the percentage of correct answers ranges between 30% and 40% and increases up to the third grade, while the achievements of the fourth grade students were slightly lower. In the first part of the task, the students were able to successfully recognize the illustration with the appropriate position of the shadow (85%), based on the position of the flashlight directed towards the cup. However, in the second part of the task the students have encountered more problems, since the request was reversed, and they had to determine (draw) the position of the flashlight that produces certain shadows of the cups (three cases) when illuminated. Less than half of the students correctly determined the position of the flashlight when the shadow was behind the cup, while they were slightly more successful in examples where the shadow of the cup was on the side or in front of it (60% and 67% respectively).

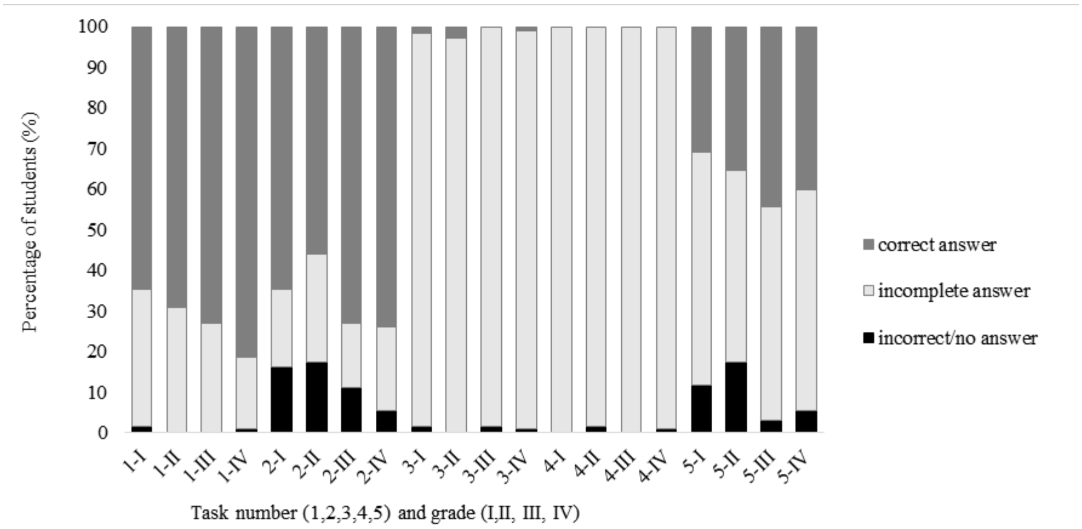

Figure 4. Distribution of students' achievements by answer categorization for the first five tasks (1-5) on the knowledge test

An overview of students' answers on the knowledge test for the remaining five questions, shown by categorization and the grades, is given in Figure 5. The sixth task proved to be the most demanding because not a single student solved it completely correctly, and the percentage of incomplete answers ranges between 10% and 50% and it rises with grade. This indicates that the students are not able to relate the distance of the light source to the size of the shadow, and the example with the light source further away from the object was solved correctly by a slightly higher number of students. Within the seventh task, the students supposed to draw the line to represent the rectilinear propagation of light from different sources. This task was done correctly by 70% to 80% of the students, and the proportion of correct answers increases with grade. This result is similar to the first task and could be the result of the teaching influence, given that the contents of light sources and its straight line propagation are sufficiently represented in teaching and learning programs.

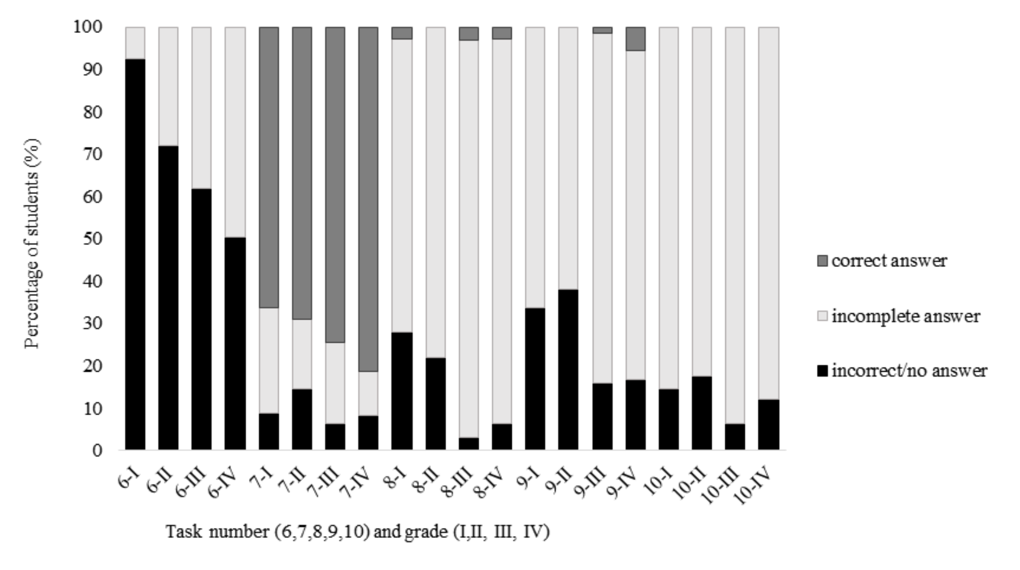

Figure 5. Distribution of students' achievements by answer categorization for the last five tasks (6-10) on the knowledge test

The proportion of correct answers in the eighth task is exceptionally small, incomplete answers are dominant in all grades, while the percentage of incorrect answers is many times higher in the first and second grades compared to the third and fourth. In this task, students were required to draw the shadow of a tree in relation to the position of the Sun (morning, noon and afternoon). When drawing a shadow in the morning, first graders incorrectly estimated (drew) the size of the shadow (90%), the position of the shadow (75%), did not connect it to the tree (78%) and it was not represented as a shaded surface (81%). The situation is similar with the students of the second grade (incorrectly drawn size of the shadow - 84%; position of the shadow - 56%; disconnection of the shadow with the tree - 78%; representation of the shadow as an unshaded surface - 91%). The percentage of wrong beliefs about the characteristics of the shadow is slightly lower in the third and fourth grades: the size of the shadow (III - 76%, IV - 73%), the position of the shadow (III - 51%, IV - 52%), the connection of the shadow with the tree (III - 68%, IV - 68%) and shading of the shadow surface (III - 81%, IV - 69%). When drawing a shadow at noon, students of the first, second and third grade made the same mistakes and to a similar extent as in the previous part of the task, while those from the fourth grade were more successful in drawing the shadow connected to a tree (51%), as well as in positioning the shadow (70%). In the last part of the task (drawing a shadow in the afternoon), identical and equally prevalent errors were observed as in the previous two parts. In the ninth task, apart from the exceptionally small percentage of correct answers in the third and fourth grades, the problem of students when drawing the proper position and shape of the shadow of different geometric bodies is evident. The occurrence of incorrect answers is significantly higher among students in the first two grades compared to the older students. In this task, as in the previous one, the students of all four grades made identical mistakes when drawing shadows (size and position of the shadow, connection with the body and shading of the surface of the shadow), but it emerged that drawing the shape of the object's shadow is generally not a problem for them. In the tenth task, the students had an easier task compared to the previous two, in the sense that the shadow of the tree was already drawn and they only had to draw the shadow of the girl standing next to it. However, unexpectedly, there were no correct answers in any grade, while the proportion of incorrect ones ranged between 5% and 20%. A large percentage of students in all grades correctly drew the shape of the girl's shadow, however, in the first grade, none of the student made the connection of the shadow with a girl, in the second only two students did it correctly, in the third only four, and in the fourth five of them. When it comes to the shadow size, 82% of first graders, 68% of second graders, 57% of third graders, and 51% of fourth graders drew a shadow much larger or smaller than the correct size. Drawing the correct position of the shadow was also a large problem, with only 12% of the first graders doing it correctly, 18% of the second graders, 35% of the third graders, and 40% of the fourth graders. The students made a significant number of mistakes when it comes to the details of the shadow, such as drawing the elements of the face on it and lack of the shading of the shadow surface (I - 85%, II - 90%, III - 86%, IV - 68%). A possible explanation for the worse results, in the actually easier task comparing to the previous two, could be found in the children's need to draw details (such as: eyes, mouth, sleeves, collar) on girl's shadow they have previously drawn.

Discussions

The analysis of students' achievements on the knowledge test about light revealed that there is no statistically significant difference in terms of success among students from different schools, while this difference exists among students of different grade (age), in favor of higher grades. The absence of differences between schools is expected because it can be assumed that the learning conditions in them are similar and that teaching in all schools takes place in accordance with the learning programs. Differences between school grades (in favor of older students), could primarily be explained by the development of their cognitive abilities, but also by the influence of school learning. The obtained results indicate that the majority of respondents consider the Moon as a source of light, confirming the findings of some previous studies (Sahin et al., 2008; Pine et al., 2001), while there were no difficulties in identifying other examples. When it comes to the transparency of materials, it was found that students successfully distinguish between objects made of transparent and opaque materials, while many of them had difficulties recognizing partially transparent objects. Students have demonstrated good results while drawing the lines, tried to illustrate the rectilinear propagation of light from different sources, which is a prerequisite for the correct acquisition of more complex concepts such as the nature of vision and shadow formation (Kokologiannaki and Ravanis, 2013; Grigorovitch, 2014). The largest number of misconceptions among all students, from the first to the fourth grade, was observed when drawing the shadows. Likewise to a number of previous studies (Pine et al., 2001; Herakleioti and Pantidos, 2016; Delserieys et al., 2017), the most common misconceptions were noted when drawing the size and position of the shadow, the connection of the shadow with its object and when sketching the details of the shadow. The results also indicate that it was easier for students to determine the position of the shadow if they have insight into the position of the light source and the object, than vice versa (when they have to determine the place of the light source knowing the position of the shadow). In addition to the shadows' drawing, the students experienced difficulties with proper correlation of the shadow's size on the wall and the light source distance from the object, what is in agreement with earlier research (Herakleioti and Pantidos, 2016).

Conclusions

The conducted research showed that the success of students on the knowledge test about light depends on their grade (age), but not on the school they come from. On the whole, the students' test achievements were satisfactory in all subpopulations. Nevertheless, it was found that, among students from the first to the fourth grade of primary school, the incorrect beliefs about light are present to varying degrees and are almost identical regardless of grade. By looking at the achievements of students on individual tasks, the most dominant misconceptions about light phenomena were identified as: the Moon, a window and a mirror as sources of light; water, a visor, eyeglasses and a curtain as opaque entities; the Moon, a candle flame and fire as natural sources of light; incorrect connection of the shadow's position with the light source's position; size wise incorrect drawing of the shadow related to the distance between the light source and the object; inaccurate representation of the position, size, shading, details and connection of the shadow to the object. The obtained results indicate the need for more frequent checking of student knowledge as well as the application of different types of active learning (Randler and Hulde, 2007; Logar and Ferk-Savec, 2011; Hsu, C-Y., C-C. Tsai, and J-C. Liang, 2011) in classroom teaching. It is known (Wagaba, F., Treagust, D.,F., Chandrasegaran, A.L., and Won, M., 2016) that students often give correct answers on knowledge tests (declarative knowledge), but they are unable to explain why their answers are correct (procedural knowledge). That's why, regardless of the varied and rich knowledge about children's understanding of light concepts obtained by the applied test, it would be useful to design and use more precise tests such as two-, three- and four-tier tests (Kaltakci-Gurel, D.,Eryilmaz, A. and McDermott, L.C., 2017), or even combine different techniques (tests and semi-structured interviews) that would provide insight in students' metacognitive strategies (Wagaba et al., 2016). A combination of test and interview is more appropriate for the age group that we dealt with in this research, because students at early school age are not capable of explaining their answers precisely and in detail. In addition, all teachers should have the opportunity to participate in a conceptual course in geometrical optic, other topics in physics, as well as to other sciences, in which they are guided in constructing a conceptual model from their own observations (Kaltakci-Gurel et al., 2017). Based on our study, it is recommended to construct an inventory of children's misconceptions and, accordingly, to create innovative teaching models, what could enable the successful misconceptions' overcoming.

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, A.B., Y.T. and N.K. methodology, A.B., Y.T., N.M. and N.K.; formal anal-ysis, Y.T. and E.S.; writing—review and editing, A.B., Y.T., N.K. and E.S. All authors have read and agreed to the published version of the manuscript.

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Perceptions of School Staff Related to Non-Suicidal Self-Injury (NSSI) Research: Implications for Promoting School Mental Health

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Abstract: Although non-suicidal self-injury (NSSI) is recognized as a significant concern among adolescents worldwide, research on school-based responses remains limited, particularly in developing countries such as Serbia. Schools often lack mental health resources, clear protocols, and support for staff, leaving teachers feeling isolated and unprepared to manage NSSI. Collaboration between researchers and practitioners in improving conditions for adequate response is highly important. Therefore, it is essential to examine how practitioners perceive it. This study aimed to explore school staff perceptions about the role of the research in addressing NSSI within school context. Sample consisted of 556 school staff members (84.2% female; Mage = 45.51 years) in Serbia who were asked why researchers should explore school staff experiences with students who engage in NSSI. Responses were analyzed using qualitative content analysis. Four main categories emerged: NSSI knowledge, Prevention, Identification and early intervention, and Treatment. NSSI Knowledge captures teachers' understanding of the need for exploring prevalence, key factors and causes of NSSI, while Prevention points to the need for training and increased NSSI awareness in schools. Identification and early intervention emphasize participants' role in recognizing signs, mobilizing resources, and following clear protocols. Treatment refers to ways of supporting students who engage in NSSI. Overall, school staff recognize NSSI as a significant issue and perceive themselves as frontline responders but highlight the need for greater support in fostering their competencies, getting wider access to the resources, and institutional support for effective prevention and intervention.

Keywords: *non-suicidal self-injury (NSSI), school staff, researchers, Serbia.*

Introduction

School-based research related to mental health

Mental health issues are highly prevalent - one in five persons will experience mental health issues in their lifetime with most cases likely to emerge between the ages of 16 and 24 (Andrews et al., 2014). Approximately 241 million young people (13.4%) worldwide are affected by some form of mental health issue (Polanczyk et al., 2015). Variety of disorders are observed among students, including anxiety disorders (6.5%), conduct disorders (5.7%), ADHD (3.4%), and depressive disorders (2.6%) (Polanczyk et al., 2015). Similarly, a recently published systematic review and meta-analysis reported 15.5% prevalence of mental disorders among children and adolescents aged 5 to 18 years in Europe. Consistent with previous findings, anxiety disorders and ADHD were identified as the most prevalent conditions (Sacco et al., 2024). Furthermore, it is shown that the prevalence of mental disorders among young people aged 10 to 24 years in European countries is rising (Castelpietra et al., 2022). Schools are increasingly regarded as critical community settings for the identification and provision of mental health support among youth, frequently serving as the primary access point for mental health screening and intervention. Evidence

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from a cross-national study involving schools in ten European countries demonstrates that a substantial proportion of schools perceive their current mental health support for students as insufficient (Patalay et al., 2016). When it comes to the level of priority given to mental health provision in their school, only 25.7% of schools in Serbia indicated high or essential priority (Patalay et al., 2016).

Despite the increasing amount of research on mental health in school settings, a substantial gap persists between scientific findings and their practical application within educational environments (Atkins et al., 2010). Walker (2004) discussed that the field of mental health has one of the widest research-practice gaps, with a significant time lag between empirical validation and implementation. Most of the research on mental health in schools focuses on raising awareness within the community about the prevalence of these issues, which could lead to improving students' mental health outcomes in the school context (Marshal, et al., 2017; Rossen and Cowan, 2014; Sanchez, et al., 2018). However, such research can be expensive, time-consuming, and often less effective than anticipated (Sanchez, et al., 2018). Policies and public health initiatives (Adelman and Taylor, 1999; 2006) are frequently overlooked, inconsistently followed or primarily focused on teachers' perspectives on mental health (Shelemy et al., 2019) which, while important, are not always implemented in practice. Moreover, there is a link between students' mental health and school performance (e.g. Owens et al., 2012). However, research that directly examines the impact of mental health in school settings often treats mental health and school behavior as separate issues (Hoover and Bostic, 2021). In other words, instead of looking at these areas independently, school performance and student mental health should be viewed as interrelated goals, though it is rarely the case. This suggests that effective education must incorporate the emotional well-being of students, as it plays an important role in supporting academic achievement (Atkins et al., 2010).

Teachers are often recognized as key figures in promoting and supporting students' mental health (e.g., Fortier et al., 2016), but they usually lack proper training and overall support for this kind of role (e.g., Radanović et al., 2025). One source of support comes from the data of the academic research on topics related to students' mental health. However, when it comes to teachers using research to enhance their practice, some studies suggest that while teachers show positive attitudes towards academic-type research (Kallitsoglou and Mahmud, 2023), they are less prone to use this kind of resource in their school decision-making (Cain, 2015). Improving the relevance of academic research findings could be especially important for mental health problems such as non-suicidal self-injury (NSSI), since early manifestations of self-injurious behaviour are most likely to surface in everyday classroom interactions, and teachers, positioned as frontline observers, need concise, practice-oriented evidence to recognize warning signs, respond safely and empathetically, and facilitate timely referral to specialized support (Elyoseph and Levkovich, 2024).

Non-suicidal self-injury and school-based research

It is expected that, within the school context, the most frequently studied mental health issues are those that occur most often, such as anxiety and depression, which are the most prominent disorders among children and adolescents (Child and Adolescent Health Measurement Initiative [CAHMI], 2021–2022). However, one of the increasingly recognized issues that is receiving more attention and poses a particular risk during this developmental period is NSSI. As defined by the International Society for the Study of Self-Injury (ISSS, 2024), NSSI is the *deliberate, self-directed damage of body tissue without suicidal intent and for reasons not socially or culturally sanctioned*. Although NSSI is different from suicidality, and it does not imply a suicidal motive, research has shown that it correlates robustly with suicidality (Harris and Ribeiro, 2021), which is one of the reasons why it is so important to pay attention to it. Although cutting skin is the most common method of NSSI used among adolescents, some studies have shown that girls are more likely to use cutting while boys more often engage in hitting and burning themselves (e.g., Barrocas et al., 2012; Sornberger et al., 2012). Meta-analysis showed that global NSSI prevalence among adolescents is approximately 17 to 18% (Swannel et al., 2014). Teachers are often the first to notice signs of NSSI. Not only do more than a half of teachers in many studies report dealing with NSSI, but they also perceive it as an increasing issue (Berger et al., 2014; Heath et al., 2006). They often report being concerned, frustrated by lack of support, lacking knowledge and confidence and have limited professional support (Berger et al., 2014; Elyoseph and Levkovich, 2024). Importantly, teachers often report willingness to help and get involved, but they emphasize the need for additional education, training and guidance (Berger et al., 2015; Elyoseph and Levkovich, 2024; Heath et al., 2006; Radanović et al., 2025; Simundic et al., 2024). In response to that, many international guidelines for addressing NSSI in schools have been published over the last decade (De Riggi et al., 2017; Hamza and Heath, 2018; Heath et al., 2020; Hasking et al., 2019, 2021). Last year, a proposed protocol for procedures in schools in Serbia was published (Radanović et al., 2025).

Why exploring this topic in Serbia: research objectives

Our previous studies (Radanović, 2025) have shown that Serbian schools are generally unprepared to address mental health issues. The findings of the Health Behaviour in School-aged Children (HBSC) study in the Republic of Serbia highlight the need for targeted interventions at both the school and community levels to enhance social support within the school environment, alleviate academic pressure, and prevent bullying (Skoric et al., 2023). There are no mental health specialists employed in schools in Serbia. Mental health is not frequently discussed within the school context, and prevention or intervention programs are typically implemented by NGOs - and none of these programs specifically address NSSI. No school or national-level guidelines or official protocols are established on how to adequately respond to NSSI among students. Epidemiological studies on NSSI in Balkan countries are rare. In Serbia, there is still no nationally representative data on the prevalence of NSSI among adolescents, although the first such study is expected to be published soon. However, it is shown that the lifetime prevalence among adults is about 4% when measured using a yes/no question, and 14.5% when using a checklist of NSSI behaviors (Radanović et al., 2022). Given the impression that school staff are largely left to manage these issues on their own with minimal external support, an important question arises - what can educational researchers, one of the key actors in the process of improving education, do to help? We have recently proposed an NSSI protocol tailored to Serbian schools (Radanović et al., 2025) to help school staff respond to NSSI more effectively. However, like any other protocol, its implementation and practical use will largely depend on close collaboration between researchers and practitioners. This research aimed to better understand the attitudes of teachers towards the research of the NSSI in schools, a problem which can consequently help us identify barriers to implementation, improve the practical relevance of academic findings, and support the development of more effective, context-sensitive interventions in Serbian educational settings.

Materials and methods

Sample. We invited all schools in Serbia to participate in this research, using a comprehensive national list (school sampling frame) of schools. A database of all state and private primary and secondary schools in Serbia was compiled, including publicly available email addresses. An email was sent to inform principals about the study, and informed consent was requested from each principal and school staff member. A poster summarizing key information about the research project was also attached. As the study was part of a larger project on mental health literacy and introduced with a focus on general mental health topics, it likely attracted a more diverse sample, including participants beyond those specifically interested in NSSI. Although all schools in Serbia were invited to participate, only 61 elementary school principals and 32 high school principals gave consent to distribute questionnaire links to their staff members. The remaining schools either declined or did not respond to our calls. The final sample consisted of 556 school staff members (84.2% female), 24 to 70 years old (M=45.51, SD=9.75).

Measures. Based on the example of previous studies (e.g., Berger et al., 2014), participants had to read the definition of NSSI before answering questions (*direct and deliberate damage of bodily tissue without suicidal intent such as cutting, head or hand banging, severe scratching, etc.*). As in previous studies (Berger et al., 2014), definition was outlined to ensure participants' answers are indeed related to NSSI in case they are not familiar enough with the concept. The questionnaire consisted of structured introductory questions and a single unstructured open-ended question. Introductory questions are related to participants' age, gender, and years of professional experience. To explore staff's perception of scientific research related to NSSI and the importance of exploring their experiences, we asked *Why do you think it is important for researchers in this field to explore your experience with students engaged in NSSI?*

Procedure. School principals forwarded a link to the online consent form and online questionnaire to all school staff members. The questionnaire was launched online using SoSci Survey (Leiner, 2020). Staff members completed the questionnaire anonymously and voluntarily. At the end of the survey, participants were provided with authors' email addresses and websites containing detailed information about the research project. Following data collection, all participants received a debriefing.

Debriefing. The debriefing was provided in the form of a written text prepared by researchers and mental health experts, focusing on the mental health of children and adolescents. As the study was presented as part of a broader mental health literacy project, the debriefing included information not only on NSSI but also on mental health issues more generally. The debriefing emphasized the importance of collaboration between researchers and practitioners in addressing students' mental health challenges. Finally, references and recommendations for further reading were provided.

Qualitative analysis. Answers to the open-ended question were organized and quantified using qualitative content analysis (Schreier, 2012) and software MAXQDA 2024 (VERBI Software, 2024). Following data familiarization, two independent coders developed and named the categories through multiple rounds of discussion. Then, each of the two researchers independently applied the agreed-upon categories to all responses. To assess the level of agreement, the Intraclass Correlation Coefficient (ICC) was calculated using IBM SPSS Statistics, version 29.0. There was no character limit for responses to the open-ended questions. The number of coded responses exceeded the number of participants, as some answers contained multiple distinct ideas or perceptions. These were accordingly coded into more than one category.

Results

All responses unrelated to the question were excluded from the analysis. In total, 423 responses from 400 participants were categorized. The interrater reliability was .93, indicating an excellent level of agreement between the coders. Final categories, subcategories, their frequency, and examples for each are presented in Table 1. Four overarching categories emerged: *NSSI knowledge*, *Prevention*, *Identification and early intervention*, and *Treatment*. Responses within the *NSSI knowledge* category reflected participants' interest in understanding the phenomenon of NSSI among students, specifically, its prevalence, characteristics, and underlying causes. School staff emphasized that researching NSSI in school settings helps to gain a clearer understanding of why students engage in NSSI and to identify those in need of support. The *Prevention* category included responses highlighting the importance of raising awareness and educating both staff and students, as NSSI remains a rarely discussed topic in schools. Participants indicated that exploring the issue within schools can guide the development of effective prevention strategies and help assess teachers' training needs and schools' preparedness to respond appropriately. The *Identification and early intervention* category encompassed three main subcategories: Teachers as gatekeepers, Mapping school resources for mental health support, and providing a protocol for school staff response. These responses underscored the role of teachers and school systems in recognizing warning signs, mobilizing existing resources, and ensuring that staff have clear guidance for action. Finally, the *Treatment* category comprised ideas related to offering help and support to students struggling with NSSI. Responses that addressed broader factors affecting students' or teachers' mental health were grouped under category *Other*.

Table 1. *School staff views on sharing experiences with researchers about student NSSI (non-suicidal self-injury)*

Category	Subcategory	N	Example quote
NSSI knowledge	Prevalence	23	*To determine the prevalence rate of self-injury among young people…*
	Phenomenology	17	*To better understand the problem and get a clearer picture*
	Etiology	6	*To understand why a person engages in self-harm*
	Other	24	*To write a research paper*
NSSI prevention	Raising awareness	50	*Because it is rarely discussed in schools*
	Education	30	*I assume it is to better understand how much training teachers need to provide support in these specific situations*
	Prevention in general	74	*To prevent such situations*
Identification and early intervention	Teachers as gatekeepers	38	*To identify them early and provide or refer them to appropriate support*
	Mapping school resources for mental health support	80	*To have the clearest possible picture of the situation in schools*
			To understand how capable we are of helping children who self-injure
	Providing protocol for school staff reaction	30	*To give us guidance for future work*
NSSI treatment		97	*To provide help to such students*
Other		32	*It is all about family*

Discussions

This study aimed to explore school staff's perceptions of the NSSI research within school context – an issue that is increasingly present in school settings but remains under-researched, particularly within the Serbian education system. Our findings provide insight into how school staff perceive the necessity and potential implications of scientific research related to NSSI.

School staff emphasized the relevance of conducting research towards enhancing knowledge on NSSI for understanding its prevalence, phenomenology, and underlying risk factors, as well as for the knowledge base for further research. In relation to prevention, participants highlighted the need for raising awareness and targeted education, noting that NSSI remains insufficiently addressed within the school context and that additional teacher training is essential. They viewed themselves as key actors in the early identification and intervention process, stressing the importance of timely detection, systematic mapping of available resources, and the establishment of clear response protocols. Regarding treatment, staff underlined the necessity of providing appropriate support to students who engage in self-injury, while also recognizing the significant role of the family and other systems in addressing and managing these behaviors.

Participants from the present study shared understanding on the importance of gathering NSSI knowledge base, including the importance of exploring prevalence rate, e.g. "To find out how many cases of NSSI are present in student population". Although the is still no nationally representative data for adolescents in Serbia, what we do know, based on studies conducted among adults, is that the prevalence of NSSI ranges from 4% to 14.5%, depending on how the questions are framed (Radanović et al., 2022). Based on the respondents' answers, it is reasonable to question to what extent these findings are known to those for whom they are relevant, as well as how effectively research results are disseminated and shared with the groups they are intended to benefit. School staff also emphasized the importance of examining NSSI phenomenology and risk factors of NSSI, noting that such insights could be helpful to them. Research evidence indicates that a wide range of risk factors, including mental disorders, low health literacy, adverse childhood experiences, bullying, problem behaviors, negative attitudes toward school, low academic achievement, and female gender, are associated with NSSI (Baetens et al., 2021; Wang et al., 2022). Among these, school-related factors are particularly noteworthy, underscoring the relevance of the school context for understanding NSSI. Knowledge about factors contributing to NSSI is often derived from research conducted with students in school settings, which teachers appear to have recognized well.

The need for prevention efforts related to NSSI is also recognized. School staff members believe that greater emphasis on awareness-raising initiatives would yield stronger benefits for schools. One of the participants stated *Because it is something that happens, yet is not spoken about enough, and as is often the case when it comes to mental health, it is frequently concealed*. Awareness efforts are contributing to this reported increase in mental health problems. Due to prevalence inflation hypothesis (Foulkes, and Andress, 2023), it is expected that mental health awareness efforts will contribute to the rise in reported NSSI cases which is a beneficial outcome. Greater public awareness of NSSI perceived by students include creating websites and social networking pages, petitions, online support groups, and campaigns to raise funds and knowledge of NSSI (Berger et al., 2014). At school level, NSSI prevention programs based on psychoeducation show evidence on reducing the likelihood of students' future NSSI engagement (Baetens et al, 2020). Interestingly, participants emphasized that effectively addressing NSSI in Serbia goes beyond awareness-raising initiatives. Many participants identified education and professional development as important, suggesting that research on NSSI in schools should inform the design of staff training to strengthen their capacity to support students' mental health, for example *to provide a foundation for planning staff training aimed at developing the skills necessary to promote students' mental health within the school setting*. Different forms of NSSI education for teachers and other members of school staff could be offered. In recent years, online learning modules have emerged as an accessible and effective option. For example, Burn et al. (2025) developed and evaluated an e-learning module titled *Supportive Response to Self-Harm*, while Price et al. (2022) provided an online training program for secondary school teachers. However, in Serbia there are still no official mandatory training programs on NSSI for primary and secondary school teachers. Teachers may attend such programs outside the school system and typically have to finance them themselves, while the number of available programs remains very limited. Within the *Prevention category*, participants emphasized several systemic factors that influence how schools and society respond to NSSI. They highlighted the need for comprehensive, multi-level approaches such as whole-school prevention programs, peer-based initiatives, and collaboration with families and the wider health and social care systems. Evidence supporting these approaches can be found in recent studies, for instance, whole-school NSSI prevention programs (Aspeqvist et al., 2025), peer-based NSSI prevention programs (Cipriano et al., 2022), and intersystem cooperation models involving schools and other support networks (Bowden et al., 2025). These findings indicate that teachers are indeed able to identify effective strategies for preventing NSSI, but they also recognize that these strategies are not implemented in their school environments. They call on relevant stakeholders, including researchers, to engage in addressing this issue.

Teachers in the present study recognize that they should be engaged throughout the research process, as they have direct insight into students' well-being and mental health which previous studies have similarly indicated (Ching et al., 2024; McLaughlin and Black-Hawkins, 2007; Vanderlinde and Van Braak, 2010). One of the participants in the present study comment that *children spend a lot of time daily in school, and it is a setting where signs of self-injury may be detected, and where students may also feel free to share their problems and seek help*. In this context, teachers are left to fill roles for which they are neither trained nor adequately supported (Giles-Kaye et al., 2022). Berger and colleagues (2014) described this situation as teachers feeling like they are "working in the dark," which may reduce both their willingness to engage and students' intentions to seek help. Many teachers feel overwhelmed and poorly equipped to respond effectively to students' mental health needs, NSSI included (e.g., Berger et al., 2014, 2015; Elyoseph and Levkovich, 2024). School staff mostly recognize the importance of their role and empathize with students, e.g. one participant says *we have the opportunity to notice, to prevent, to help… because we have a relationship with children that is, or should be, based on trust; because we spend time with them; because, after all, we are educators, human beings, and humanists*. On the other hand, the absence of mental health professionals in schools and lack of clear protocols leave them uncertain about how to act, while the broader school culture often encourages silence rather than open discussion of difficult topics. Participants from present study shared *Because it is silenced - it is a "taboo topic" both in society and in schools. My experience is that it is preferably "not discussed" at staff meet-*

ings, since addressing it would require the school to initiate a protocol that is considered "too complicated" and "something we don't need right now" (in the words of my school principal). Although many participants called for training and educational support, the implication is not that teachers should become therapists, but that they need appropriate tools and protocols to respond to NSSI confidently and effectively (Costa et al., 2020). This finding aligns with data showing that most teachers recognize the importance of mental health in learning, and at the same time feel unprepared to help them (Andrews et al., 2014; Giles-Kaye et al., 2022). Additionally, responses suggest another important point: NSSI is a stigmatized behavior, and it is necessary to address this stigma as part of prevention and intervention efforts.

School staff perceive research on NSSI as important for improving interventions designed for students engaged in NSSI, emphasizing the need for better support to the students. Participants from the present study pointed out that the research is aimed to improve work with students who engage in NSSI, but it is essential to recognize that schools alone cannot be expected to carry the full burden of mental health support. Although this study aimed to explore collaboration between researchers and practitioners, and the question targeted practitioners' perceptions of their role in our research, the responses largely centered on a different issue - the challenging position of school staff in responding to students' mental health problems and their calls for support from various stakeholders, including researchers. Several unclassified responses in the present study addressed the challenging position of school staff and feelings of exhaustion. For instance, one teacher described the researchers' intention to explore NSSI as follows: *because you plan to burden already overburdened teachers even further*. The response indicates that research is sometimes viewed by school staff as an additional burden, and that the significance of their participation or the data they provide may not always be adequately highlighted or effectively communicated. This serves as a reminder to researchers to invest more effort in the planning and data collection phases of school-based studies. Previous studies have shown that education professionals also require support (e.g., Costa et al., 2020). We should not only attend to their educational needs but also contribute to creating a healthier and more supportive work environment. Even in more developed countries (e.g. Australian) lack of leadership and cohesion from actors such as the Ministry of Education or Ministry of Health with a lack of clarity about solutions to increase access to support services for students, unclear roles and responsibilities and lack of best practice guidance available to schools about managing NSSI (Bowden et al., 2025). Proposing a national strategy involved with care of students engaged in NSSI, is recommended to be followed with school autonomy in flexibility of their responses to the needs, available resources and context (Bowden et al., 2025). Sanchez and colleagues (2018) demonstrated that some school-based mental health interventions can be expensive, time-consuming, and of limited effectiveness, underscoring the importance of designing interventions that are feasible, cost-effective, and compatible with existing educational structures. Our participants echoed this concern, indicating that research leading to increased administrative burdens without clear benefits will likely face resistance. Therefore, future studies must adopt an applied focus, be co-designed with educators, and aim to produce context-sensitive tools that are straightforward to implement. Methodologies such as action research, design-based research, and participatory approaches are particularly well-suited to these objectives (McLaughlin and Black-Hawkins, 2007).

Limitations

The first limitation of this study concerns the sample. A much smaller number of schools agreed to participate in the study than expected, so the dropout rate among those initially contacted was high. It is likely that the staff who chose to respond were those already concerned about mental health or NSSI, which may have introduced a self-selection bias. Several factors likely contributed to the low level of engagement, and the feedback from participants in this study provides insight into the reasons for the low response rate. First, there is a notable sense of skepticism toward research among school professionals. Participants in present study reported having taken part in previous studies without ever receiving feedback or observing meaningful change, leading to doubts about the value and purpose of participation. Second, mental health, and especially sensitive topics like NSSI, remains stigmatized and uncomfortable to address within many school environments. Third, administrative overload significantly contributes to low participation. With increasing responsibilities and bureaucratic demands, school staff often view research participation as an added burden. Furthermore, the lack of systemic support and absence of national-level mental health initiatives leave many schools feeling isolated and without clear guidance on how to engage in research collaborations. Finally, open-ended questions provide valuable insights, but they lack the structure needed to systematically assess the prevalence of specific beliefs or attitudes. While our findings offer some understanding of how school staff perceive NSSI research, it would be more useful to conduct interviews to obtain more concrete and detailed responses that would provide clearer insights into how teachers perceive the role of the researchers. These important questions remain open and should be explored further through longitudinal, mixed-method studies that aim to deliver more practical and context-sensitive insights. Involving teachers as active partners through, for example, participatory research, would ensure that proposed interventions are contextually relevant, and sustainable within existing educational frameworks.

Conclusions

In summary, this study offers valuable insights into school staff perceptions of research on understanding and addressing NSSI among students in the Serbian educational context, including their role in it. Results indicate that they recognize the importance of research on NSSI, the valuable information such research provides, and its role in improving school practices related to recognition, prevention, and treatment. Additionally, they expressed a strong interest in professional development and systematic training to enhance their ability to respond effectively to students' needs, while acknowledging that schools cannot shoulder this responsibility alone. At the same time, they draw attention to the need to protect and support educators, who often feel overburdened and insufficiently equipped to manage such complex challenges.

Insights from this study provide the implication for developing and evaluating structured NSSI education modules for school professionals, which can enhance staff competencies and strengthen schools' capacity to promote students' mental health. Importantly, researchers must consider the workload, needs, and well-being of school staff. Understanding teachers' perspectives can guide researchers in developing context-sensitive, school-based prevention and intervention strategies. These findings revealed the importance of designing research with schools, not merely about them.

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Conflict of interests

The authors declare no conflict of interest.

Data availability statement

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

Institutional Review Board Statement

This research has been approved by the Ethics Committee of the Institute for Educational Research (Decision No. 96 dated February 9, 2023).

Author Contributions

Conceptualization, A.R., I.M., M.T., M.K.L., and J.M.; Data curation, A.R., I.M., M.T; Formal analysis, A.R., I.M., and M.K.L.; Investigation, A.R., I.M., M.T., M.K.L., Methodology, A.R., I.M., M.T., and

M.K.L.; Project administration, A.R., I.M., M.T., Writing—original draft preparation, A.R., I.M., M.T., M.K.L and J.M.; writing—review and editing, A.R., I.M., J.M., M.T. and M.K.L. All authors have read and agreed to the published version of the manuscript.

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Artificial Intelligence, Social Change, and Sociology Education: Toward Digital Sociology in The age of Deglobalization

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Abstract: This paper investigates the transformative impact of artificial intelligence (AI) and deglobalization processes on contemporary society, with a particular focus on redefining the discipline of sociology and educational paradigms. Through a critical analysis of opposing currents of digital integration and geopolitical fragmentation, and by synthesizing insights from the sociology of technology, education, and digital transformation theory, the study offers a conceptual framework for digital sociology as a new theoretical and methodological domain that examines how algorithms, platforms, and intelligent systems shape social relations. Three key aspects are analyzed: (1) the role of AI in reconfiguring social structures, (2) the consequences of deglobalization on the development of digital technologies, and (3) the necessity of reforming sociology education to prepare future researchers for a critical understanding of these processes. The study adopts an interdisciplinary approach, combining theoretical analysis with case studies. Its primary contribution lies in elaborating strategies for adapting sociological education to the conditions of digital transformation, fostering ethical reasoning, and promoting social responsibility.
Keywords: *Artificial intelligence, digital sociology, social change, sociology education, deglobalization.*

Introduction

Contemporary society stands on the threshold of profound transformations that are reshaping everyday life, social relations, and educational paradigms. We are witnessing an era in which artificial intelligence (AI) and transhumanist technologies are no longer confined to the realm of science fiction, but are increasingly embedded in our daily lives—altering the ways we work, communicate, make decisions, and engage with culture, media, and education (Selwyn, 2019; Slavković et al., 2023; Petrović, 2019; Ristić and Marinković, 2019; Shi et al., 2020; Šuvaković, 2024; Zdravković, et. al., 2025)—and even influencing our understanding of what it means to be human (Masliković, 2025). The magnitude of this impact is anticipated in the prediction of computer scientist Mark Weiser (1991, pp. 94–105), who foresaw humanity entering an era of ubiquitous computing, in which digital technology would become so interwoven with human life that its pervasive presence would largely go unnoticed.

On the other hand, *deglobalization* processes lead to geopolitical fragmentation and uneven development of digital technologies, further complicating this concept (Friedman, 2021).

In this context, sociology faces the challenge of integrating new technologies into its theoretical and methodological frameworks. Changes in the ways we consume media and create content, accelerated by the emergence of Web 2.0, have led to the development of *computational social sciences*—an interdisciplinary field combining sociology, psychology, political science, economics, and computational methods to study social phenomena. AI intersects with this discipline, offering new opportunities for analyzing social networks, predictive modeling, and simulating interactions within digital communities. This synergy enables a deeper understanding of how digital systems shape social communication, group integration, and

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the dissemination of information, thereby opening avenues for applying *digital sociology* in teaching and researching social change in the era of deglobalization.

Digital sociology, as an emerging branch of sociology, focuses on analyzing the impact of digital technologies on social processes, identities, and institutions (Van Dijck, 2020; Castells, 2010). This discipline investigates how algorithms, platforms, and intelligent systems shape social relations and how societies adapt to new digital realities (Zhao and Wang, 2023; Selwyn, 2019a; Skopek, 2023). Jonathan Wynn shares his experiences with the use of digital technology in sociological research and teaching, sharply noting that digital technology has introduced new challenges that sociology must examine and explore in greater depth (Wynn, 2009, pp. 448–456). Digital sociology has developed in response to the growing influence of digital technologies on social processes (Boyd, 2014), recognizing, as many theorists argue, that technology is not neutral; rather, it shapes social relations, power structures, and educational practices (Wajcman, 2017; Floridi, 2019; Skopek, 2023).

One of the key aspects of this transformation is education. The teaching of sociology, as well as other social sciences, must adapt to the new challenges posed by digitalization. This involves not only the integration of new technologies into the educational process but also the development of critical thinking that enables students to understand and analyze the impact of AI and digital technologies on society (Floridi, 2019).

In this context, the aim of this paper is to investigate how AI and deglobalization affect social communication, group integration, and social inequalities, with a particular focus on sociology education. Through a critical analysis of existing theoretical frameworks and case studies, the study provides a conceptual framework for digital sociology as a new theoretical and methodological approach to examining social change in the digital age. This is done with an attempt to map the rapidly evolving landscape of our digital and posthuman future (Serpa et al., 2025). The study employs an *interdisciplinary theoretical* framework, combining approaches from the sociology of technology, education, and digital transformation. Methodological support is based on *content analysis of the literature* and *case studies*. Since the study is theoretical and analytical in nature, quantitative methods are not applied; instead, a critical synthesis of existing research and conceptual frameworks is conducted. The focus is on three key dimensions:

1. *Social communication* – aimed at exploring how digital technologies and AI shape interactions, discourse, and access to information (Van Dijck, 2020).
2. *Group integration* – analyzing the formation of shared identities and collective networks in digital environments, with attention to potential segregation (Boyd, 2014).
3. *Social inequalities* – encompassing approaches to technology, digital literacy, and the reproduction of social inequalities through algorithmic processes and digital platforms (UNESCO, 2021; OECD, 2022).

This combination of theoretical framework and methodological approach enables an understanding of how digital technologies and AI are transforming contemporary society and the educational context, particularly sociology education. Applied in this way, the interdisciplinary approach ensures the integration of critical theory, empirical studies, and practical implications for educational programs.

The Role of Artificial Intelligence in Transforming Social Structures – Toward the Transhumanization of Society

As society approaches the threshold of transhuman development, AI becomes a key factor in transforming social structures, raising new challenges and questions (Orton-Johnson and Prior, 2013; Lupton, 2015; Marres, 2017; Selwyn, 2019a; Fussey and Roth, 2020). Scholars base their discussion on the fundamental question of societal transhumanization: are we developing artificial intelligence for the benefit of humanity, or are we merely shaping humanity through the evolution of intelligent technology? Today, we are not merely discussing advanced tools but the possibility of a symbiotic relationship between humans and machines—a concept at the heart of Society 5.0, often described as a “technology-driven, human-centered” society (Masliković, 2025, p. 42). At the core of these changes lies a fundamental question: what does it mean to be human in an era when the boundaries between humans and machines are increasingly blurred? The social implications of AI and transhumanism extend beyond technical feasibility, as they touch upon the very essence of democratic values, cultural continuity, and human dignity.

The emergence and development of digital technology represent pivotal moments in the history of human civilization, as their scope and dynamics have exerted a profound impact on all dimensions of social life. The rapid advancement of these technologies has marked the onset of a new era—the digital society—in which not only communication patterns and everyday life are transformed, but deep, systemic changes in social structures are also set in motion. Digital technology, and AI in particular, no longer serves merely as a tool for improving social practices; it has become a key agent in reshaping them. As Helbing (2021) emphasizes, digitalization and intelligent systems will not only shape human discourse and institutional frameworks but will gradually transform the very foundations of the world, paving the way toward a new social and ontological horizon of a transhumanist nature. AI redefines social and economic roles through automation, information personalization, and algorithmic management of interactions. According to Bostrom (2014), algorithmic systems have the potential to transform social structures by influencing access to resources, education, and employment. Algorithms filter the information individuals receive, shape public discourse, and often reproduce existing social inequalities (Van Dijck, 2020), as will be discussed below. As Zeqi Qiu (2022) notes, the digital society, through its networking mechanisms, penetrates traditional divisions of labor and classical forms of organizational structures, positioning the individual as a central node within the digital network (Kovačević, 2024). This creates a new social model in which the individual is simultaneously an independent unit and part of a broader, interconnected whole (Nesterova et al., 2019, pp. 19–27). Such transformation not only changes the position of the individual within society but also leads to a redefinition of the relationship between the individual and the collective, reshaping the logic of social differentiation and reconsidering the fundamental principles underlying social functioning. As digital platforms and AI algorithms shape contemporary social structures, they influence behavior, identities, and perceptions of the world, altering social interactions and information flows. At the same time, the digital divide demonstrates how access to technology and the monetization of personal data can deepen social inequalities and reshape traditional power relations.

Online communities represent new “public squares” of the internet, ranging from niche forums to large fandoms, where social ties as well as rivalries are formed and reinforced. These communities demonstrate how digital spaces enable the construction of identities, collective practices, and new forms of group dynamics, providing sociology with valuable insights into contemporary social structures. Such digital spaces also offer support networks, allowing individuals to share feelings and experiences that they would rarely discuss in real life, offering comfort and solidarity in challenging situations, thereby creating new forms of social connections and communities. These spaces transform traditional social structures by expanding access to support and altering the ways in which groups and individuals organize and connect with one another. Online activist hubs challenge the status quo, reshaping forms of participation and power relations, but they also highlight the risk of performative activism. At the same time, the digital divide and algorithmic shaping of information exacerbate inequalities and introduce new challenges to social structures. Collectively, these phenomena illustrate how digital society changes the ways communities are built, power relations are reinforced, and social life is organized. They impact online identities, which can reflect or shape our “true selves,” creating new forms of social ties and interactions. Within these digital spaces, authentic communities can emerge on one hand, while on the other, performative avatars may dominate, fundamentally altering traditional social structures and the ways people connect.

As we have seen, digital platforms and algorithms strongly influence the shaping of social relationships, creating new opportunities for connection and participation, but also new forms of inequality, echo chambers, and risks to privacy and mental health (Bjelajac et al., 2023, pp. 519–531). A central task that emerges is to study how people can govern digital spaces rather than be governed by them. Research indicates that the internet has shortened the average human attention span from 12 to just 8 seconds, reflecting the growing distraction of contemporary individuals. As communication increasingly occurs behind screens, fundamental interpersonal skills—such as reading body language, facial expressions, and vocal tone—are less frequently developed. Digital sociology, through such examples, demonstrates how technology reshapes social structures, influencing not only our relationships but also the very ways we understand one another.

Thus, the challenge of the contemporary era is not only to learn to live with technology, but also to preserve the capacity for focused, critical thinking despite it. This indicates that *digital sociology* must examine how social structures are transformed in online environments and how individuals and groups position themselves in relation to the complex and often contradictory effects of digital communication. Consequently, there is a need to develop critical competencies among sociology educators and students for understanding digital power structures, inequalities, and new forms of social engagement (Prodović Milojković, 2012, pp. 187–196; Nesterova et al., 2019).

The Consequences of Deglobalisation for the Development of Digital Technologies

The study of social relations and interactions has long been at the core of sociology; however, the widespread integration of digital technologies is radically transforming their very nature (Skopek, 2023). Considering that existing definitions of AI may be grouped according to thinking and behaviour processes, as well as success criteria (Prlja et al., 2021, p. 61), this becomes particularly relevant when analysing the consequences of deglobalisation for the development of digital technologies and the transformation of human interaction.

Instead of exclusively direct, face-to-face communication, new forms of mediated interactions are emerging that blur the boundaries between presence and absence, creating so-called “connected relationships” (Licoppe, 2004, pp. 135–156). While some authors emphasize that digital media strengthen and expand social ties (Wajcman, 2015), others point to the risk of superficiality and loneliness despite increased connectedness (Turkle, 2011). The common denominator of these perspectives is the recognition that digital media not only shape modes of communication, but also transform the very nature of social relationships (Baym, 2015). Digital platforms and AI enable new forms of social communication and group integration. Group integration in digital environments depends on access to technology, digital literacy, and the algorithmic rules of platforms (Van Dijck, 2020). Through the formation of online communities, users can express their identities in more personalized ways and experience more variable senses of belonging, while simultaneously maintaining and reinforcing offline social networks (Robards and Bennett, 2011, pp. 303–317). Boyd (2014) notes that networks facilitate the creation of shared identities, support, and collaboration within communities. At the same time, algorithmic filtering and recommendation systems may contribute to the emergence of “echo chamber” effects, in which users primarily interact with similar viewpoints, potentially leading to social polarization.

In the context of deglobalisation processes, digital technologies have become key mediators of social relations, as they increasingly shape closed, fragmented, and localised communities rather than globally integrated networks. Digital sociology suggests that mediated interactions enable new forms of connectedness and collective identity formation, yet simultaneously carry risks of superficiality and social isolation. Thus, the consequences of deglobalisation are reflected not only in the economic and political spheres, but also in the transformation of the very nature of social relations and communication, which is becoming increasingly dependent on digital media and their inherent limitations. Digital technologies also transform the boundaries between private and public life. Constant connectivity, the visibility of everyday activities, and behaviours such as clicking and sharing content lead to the “privatisation of the public and the public exposure of the private” (Van Manen, 2010, pp. 1023–1032; Boccia Artieri et al., 2021, pp. 223–230). These changes, combined with multitasking and continuous psychological pressure (Tammelin, 2018), are redefining the boundaries of personal identity and collective interaction in digital society.

In addition to social and spatial vulnerability, a new and more subtle form has emerged: *cognitive vulnerability* rooted in the lack of critical reflection. Excessive reliance on AI may reduce individuals’ capacity for critical thinking, anticipation, and ethical judgement, leading to alienation from social interactions, decreased motivation for learning, and increased exposure to harmful content, particularly among younger users. In the context of deglobalisation—where access to technology may be limited or uneven—it is insufficient to address only the social or spatial dimensions of vulnerability; it is also necessary to consider the cognitive and ethical implications of dependence on digital technologies. Building a resilient digital society requires technological progress to be guided by human values, the principle of equity, and a commitment to the common good. Deglobalisation processes are fragmenting technological ecosystems and producing regional disparities in access to digital resources (Friedman, 2021), which directly affect access to information, international cooperation, and the reproduction of social inequalities. Countries with limited technological resources face a widening digital divide, while technologically advanced nations gain an advantage in global competition (OECD, 2022). Deglobalisation also shapes cultural and social networks: the regionalisation of information and the use of localised algorithms may strengthen community identities, yet simultaneously restrict engagement with global discourse (Castells, 2010).

Social media (Milenkova et al., 2018), in addition to strengthening connectedness, also intensify polarization through the formation of "echo chambers" and extremist groups (Bail, 2021), which demonstrates how digital sociology enables the analysis of social networks and identity dynamics within online communities. Digital technology makes it possible to shape collective identity and consciousness in the online space—from preserving cultural ties and memorial spaces to generating collective enthusiasm. It examines how these practices reshape social relations, strengthen the sense of belonging, and connect individuals with a wider social context in the digital age (Ponzanesi, 2020: 977–993; Recuber, 2021: 684–699; Gong, 2015: 87–103; Lorenzana, 2018). It is important to highlight that digitalization has also transformed the nature of work by introducing flexible working hours and remote work, which contributes to a better work–life balance but also raises issues of surveillance, data security (including potential risks such as identity theft, cyber attacks, and data misuse) and social isolation. In the context of deglobalization discussed here, these changes further deepen the fragmentation of the labor market, reduce labor mobility, and reinforce local inequalities, thereby shaping new patterns of social and economic relations (Demirci et al., 2023; Kovačević, 2024; Łukasz, et. al., 2019).

All these transformations in social relations and communication clearly demonstrate that the consequences of deglobalization have a crucial impact on the development of digital technologies. The fragmentation of networks, regional digital divides, and limited access to technologies shape not only technical ecosystems, but also social structures, identities, and collective consciousness. Through the analysis of these processes, digital sociology provides insight into how AI and digital media create new dynamics of power, connectivity, and vulnerability within society, making it an essential framework for understanding contemporary social change in the era of deglobalization.

Social Inequalities and Algorithmic Discrimination

Sociology's attention to social inequalities has been present throughout its history, and digital sociology continues this tradition by examining the impact of digital technologies on the reproduction and transformation of social structures, including class, gender, and race (Zhao and Wang, 2023). Particular emphasis is placed on whether digital technologies amplify existing inequalities or generate new forms of algorithmic discrimination.

The application of digital technologies not only reproduces existing social inequalities but also creates new forms of social differentiation (Hagerty and Rubinov, 2019). Initially, the concept of the "first-level digital divide" based on differences in internet access, was introduced (Castells, 2001). The information society has still not succeeded in bridging the gap in technological access or enabling full participation for all citizens. Most technological developments neglect underrepresented members of society, particularly vulnerable groups, thereby deepening existing social inequalities and the risk of algorithmic discrimination (Wang, 2021). As infrastructure developed, the "second-level digital divide" emerged—based on differences in skills and technology usage—and the "third-level digital divide," based on differences in social outcomes and benefits (Hargittai, 2001; Van Dijk, 2005; Wei et al., 2011, pp. 170–187). This phenomenon is especially pronounced in areas with less developed infrastructure and among populations with lower socioeconomic status. These inequalities are further reproduced through algorithmic processes and digital technologies. UNESCO (2021) emphasizes that the digital divide is not merely a matter of internet access but also involves skills, resources, and cultural competencies. Algorithms often reflect existing social inequalities in education, employment, and economic power (Noble, 2018). Recommendation systems on social media may favor dominant voices, while marginalized groups remain less visible, further reinforcing social stratification (Wajcman, 2017).

According to van Dijk (Jan A. G. M. van Dijk), one of the earliest theorists of digital sociology, there is a clear distinction between access to digital resources, connectivity, developed competencies, and actual usage skills—revealing deeper layers of the digital divide (Dijk, 2005; Dewey, 2021). Excessive use of digital media, particularly among young people, can negatively affect mental health and reduce face-to-face social interactions, thereby limiting the development of social skills. These effects further exacerbate existing social inequalities, as vulnerable groups are simultaneously more exposed to algorithmic discrimination and have less access to support resources[1]. Within these divides, new inequalities emerge: technologically educated users, such as software engineers and tech leaders, constitute a new

[1] As highlighted by the 2018 World Economic Forum report, an average household in the United States can generate data every six seconds. In Mozambique, where approximately 90% of the population lacks internet access, the average household generates zero digital data (see: Bridging the Gender Gap: Mobile Access and Usage in Low- and Middle-Income Countries, GSMA).

"programmer elite," whose power depends on control over technology (Burrell and Fourcade, 2021, pp. 213–237), while those without digital devices or skills suffer from digital poverty and social marginalization (Donaghy, 2021, pp. 54–55). Even individuals with higher socioeconomic status can become vulnerable due to a lack of digital literacy, including the ability to recognize misinformation and protect privacy (Lee, 2018, pp. 460–466). These processes clearly demonstrate that digital technology and AI are transforming social structures and necessitate that sociology education integrates a digital perspective and critical understanding of new forms of inequality.

Digital technologies, on the other hand, have the potential to facilitate resource sharing and expand access to information, for example through educational platforms such as MOOCs, which reduce costs and provide broader educational opportunities (Bowen, 2013). However, as observed, internet access and usage are not evenly distributed: individuals with higher levels of education are more likely to use digital resources for activities that contribute to social advancement, while others remain on the digital periphery, exacerbating existing social inequalities (Hargittai and Hinnant, 2008: 602–621; Hargittai, 2018). Furthermore, digital algorithms can subtly reproduce racial and gender inequalities. For instance, in the U.S. healthcare system, predictive models for medical needs favor white patients due to reliance on healthcare costs rather than the severity of illness (Obermeyer et al., 2019: 447–453). Similarly, advertising and employment algorithms exhibit gender biases: even when gender neutrality is maintained, men are more frequently targeted with STEM-related ads, while women are disadvantaged by the "saturation effect" and higher advertising costs (Lambrecht and Tucker, 2019: 2966–2981; Joyce et al., 2021)[2]. Although e-commerce provides economic benefits, certain aspects, such as location-based services, can deepen the digital divide and contribute to growing inequalities, reinforcing the argument that digital sociology must investigate how digital technologies not only create new opportunities but also exacerbate existing social disparities (Kozić, 2023).

As a social aspect of overcoming digital inequality, it is necessary to raise awareness of the importance of acquiring skills—primarily operational, formal, informational, communicative, creative, and strategic—in the use of new technologies, and to encourage vulnerable groups, such as older adults, to engage with these technologies (Lupton, 2012: 4). Indeed, some authors define digital inequality specifically as the gap in possession of these skills (Dijk, 2014, p. 140).

Reducing digital inequality, in turn, contributes to the reduction of broader social inequality (Krištofić, 2007, pp. 165–182).

The Necessity of Reforming Sociology Education

The multidisciplinary nature of AI, stemming from efforts to understand the nature of intelligence (Prlja et al., 2021: 58), simultaneously opens space for sociological investigations of the dynamic changes and new challenges that digital technology introduces into social life (Kozić, 2023). In response to these challenges, digital sociology has emerged, offering new perspectives for studying society. Digital sociology finds its research domain precisely in these transformations, as they raise questions about new forms of social integration, communication, and power in a digitally mediated world. It examines how technology shapes interactions among individuals and the structure of social networks.

Although the significance of public digital sociology is increasingly recognized, sociologists, overall, have devoted less sustained and systematic attention to it compared to their colleagues in communication, media, and cultural studies (Farrell and Petersen, 2010: 114–125). The development of digital sociology is relatively recent—the first scholarly article under this title was published in 2009[3] (Wynn, 2009: 448–456); the first academic publication entirely devoted to digital sociology appeared in 2013 (Orton-Johnson and Prior, 2013)[4]; and the first authored monograph was published in 2015 (Lupton, 2015)[5]. In

[2] See: Carsten Orwat, Risk of Discrimination through the Use of Algorithms.

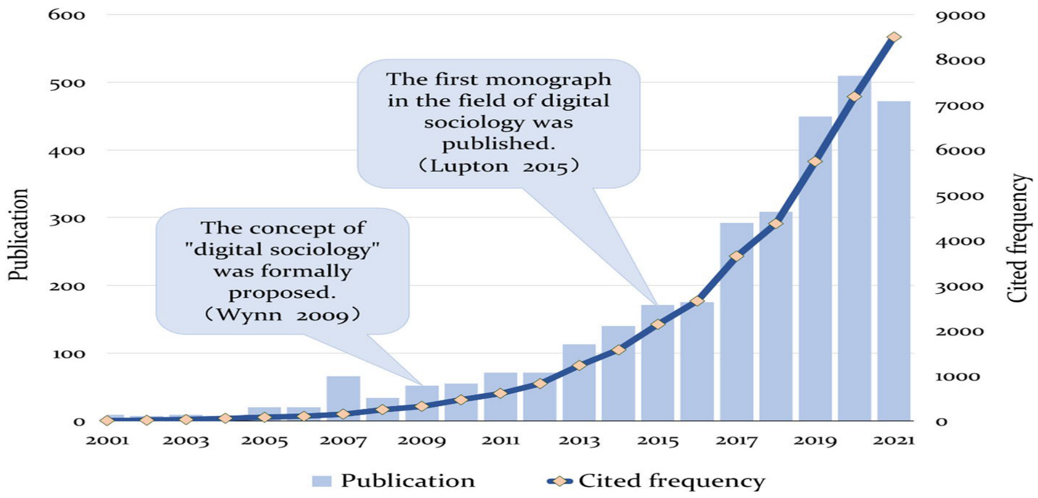
[3] The article was published in the journal Sociological Forum—"Digital sociology: emergent technologies in the field and the classroom"—and it does not provide a definition of digital sociology; rather, the author examines the ways in which digital technologies can influence both sociological research and the teaching of sociology (Wynn, 2009).

[4] Titled "Digital Sociology: Critical Perspectives" and edited by Kate Orton-Johnson and Nick Prior, this publication is an edited collection of chapters covering a wide range of topics, including theoretical approaches and ideas related to urban spaces, social relations, communities and intimacy, networked society, and social inequalities in the use of technologies, mediation, and practices in the digital era, as well as the impact of technologies on education, healthcare, and finance (Orton-Johnson and Prior, 2013).

[5] This refers to the book Digital Sociology by the Australian sociologist Deborah Lupton (Lupton, 2015).

the same year, the first academic conference dedicated to this discipline was held in New York under the Eastern Sociological Society (Daniels et al., 2015). As a field intersecting with digital humanities and anthropological studies and encompassing phenomena such as wearable technologies, augmented reality, smart objects, and big data (Duggan et al., 2015), digital sociology demonstrates that sociology education must be reformed to respond to the challenges of contemporary society.

Initially, the cited studies focused primarily on online communities, cyberspace, and issues related to the redefinition of identity in virtual environments (Lupton, 2012: 4; Petrović, 2009: 23). However, with the penetration of digital technologies into all segments of social life, the focus of sociologists has broadened to encompass increasingly complex questions concerning the social consequences of digitalization (Marres, 2017; Petrović, 2018: 557–582; Hristova, 2018, pp. 111–123; Dettano, 2023: 389–398)[6]. Over slightly more than a decade, digital sociology has experienced rapid development and growth, accompanied by the publication of various specialized works that have significantly expanded its academic and professional audience (Orton-Johnson and Prior, 2013; Lupton, 2015; Marres, 2017; Selwyn, 2019a). Simultaneously, sociological associations in various countries began establishing research branches dedicated to digital sociology, while many universities introduced courses and degree programs related to this discipline (Zhao and Wang, 2023) (see Figure 1)[7].



Data source: Web of Science Core Collection. Topic = "The digital", research field = "Sociology", publication year = 2001–2021. A total of 3050 articles were retrieved with a total citation frequency of 39,966. The search was conducted in April 2022. (Zhao and Wang, 2023).

Figure. 1 Distribution of publications and citation frequency related to digital sociology (2001–2021)

Regarding Serbia, the study by Jelisaveta Petrović (2019: 478–496), which reviews the development of internet social studies and the potential establishment of digital sociology in the country, shows that although the domestic sociological community pays relatively little attention to this field, there are clear advancements and growing trends. These findings, while indicating a certain lag compared to global developments, confirm the need for reform in sociology education so that digital sociology in Serbia can develop in line with contemporary social challenges. The way we approach these endeavors today will shape the future framework of society, its structure, and the very concept of humanity. Over the past decade, a new theme has emerged in the AI research community called "AI for Social Good" (AI4SG), where researchers aim to develop AI methods and tools that can address social problems and improve the quality of life within communities (Shi et al., 2020).

[6] Paul DiMaggio emphasizes that research on the impact of the internet predominantly focuses on five key areas: inequality, community and social capital, political participation, organization and economic institutions, as well as cultural diversity (see: Cavanagh, 2007). Thus, it appears that digital sociology is not limited solely to studying how individuals use digital technologies or analyzing the data produced by such use. Its scope is considerably broader—it interrogates the very practice of sociology, social research methods, and the position of sociologists within the digital environment. Simultaneously, it examines the ways in which sociologists employ digital media in their work, raising questions about the future of the discipline, new research methodologies, and the values and knowledge in contemporary society. These areas also constitute the foundational frameworks within which digital sociology develops its research.

[7] In 2013, Goldsmiths, University of London, established the world's first master's program in digital sociology, soon followed by the University of Edinburgh, the University of Glasgow, and Virginia Commonwealth University in the United States (Zhao and Wang, 2023).

Manuel Castells' concept of the "network society" (2000, 2001, 2012), along with the theory of "networked individualism" developed by Castells (2001) and Barry Wellman (2001: 227–252), provides a theoretical framework for understanding the changes digital technologies bring to patterns of social relations. These insights underpin the need for digital sociology to develop as a distinct discipline and for sociology education to be reformed, enabling future researchers and students to critically assess the dynamics of networked social and individual practices in the era of deglobalization. The academic community is gradually building a coherent understanding of digital sociology, yet no single definition of its nature and scope currently exists. Scholars debate two key questions: first, whether digital sociology should be viewed as a comprehensive transformation of sociology in the digital age or as a new, autonomous branch of sociological research; and second, how to precisely define the research domain of digital sociology (Zhao and Wang, 2023). Within the existing debates, some authors emphasize that if sociology aims to remain relevant in the 21st century, it must develop the theoretical capacity to explain the digital revolution and societal transformation. Gregory and colleagues (2017) note that digital sociology does not have a unified agenda and that it is more appropriate to speak of "digital sociologies." Selwyn (2019a) adds that digital sociology emerged from the research tradition of sociology but has also enabled a shift away from the paradigm of the industrial revolution toward contemporary society. In contrast, Lupton's (2015) perspective views digital sociology as one branch of sociology, providing a framework for understanding society without encompassing the entire sociological discipline in the digital age. These differing positions highlight the dynamic and plural nature of digital sociology, shaped by changes in social communication, group integration, and the transformation of social structures. Despite these open questions, interest in research in this field continues to grow worldwide, confirming its significance for understanding social change in the era of digitalization (Marres, 2013).

Some authors emphasize that digital sociology transcends the binary relationship between technology and society, encompassing the dimension of knowledge production (Marres, 2017). In this way, not only are patterns of social life shaped, but new opportunities arise for connecting academic analysis with social intervention. In this sense, digital sociology functions not only as a subject of study (Webster, 2013) but also as a methodological framework and research tool that can be integrated into sociology teaching (Lupton, 2015). This approach fosters critical thinking while also encouraging active student engagement in digital environments.

Deborah Lupton identifies four key aspects of digital sociology (Lupton, 2012):

1. The first pertains to professional digital practice, where sociologists, initially reluctant, increasingly utilize social and other digital media for teaching and research purposes (Carrigan, 2013). Today, sociological blogs are becoming more common, the presence of sociologists on platforms such as Twitter is growing, and the importance of open access is emphasized—from self-archiving publications, to participation in projects like Wikipedia, to shaping new forms of academic communication (Lupton, 2013). These developments clearly indicate that the reform of sociology education must also include training students for this type of digital practice.
2. The second aspect pertains to sociological analyses of digital usage, which includes methods for analyzing "big data," digital traces, and online communications (Willis and Tranter, 2006: 43–59). This aspect is based on studying how people use digital media and how this shapes their consciousness, identity, and social relationships (Turkle, 2011a). All of this necessitates reforming sociology education to familiarize students with new techniques for processing and interpreting digital data.
3. The third aspect relates to digital data analysis and encompasses its use for social research, whether quantitative or qualitative (such as ethnographic studies, surveys and interviews with technology users, as well as analyses of data from online interactions and social media) (Murthy and Bowman, 2014). Platforms such as Facebook and Twitter provide researchers with access to demographic and communication data, facilitating the monitoring of public sentiment, discussions on controversial topics, and "problem mapping." Tools like MentionMapp and Twitter Streamgraph are used for data visualization, showing the popularity of hashtags and the connections between words over time (Marres and Gerlitz, 2016: 21–46). This aspect highlights the need to reform sociology education so that students are equipped to use contemporary digital tools and methods in researching social phenomena.
4. Finally, the fourth aspect—so-called critical digital sociology—emphasizes the need to reassess the discipline itself in the context of the digitalization of social relations and academic work (Lupton,

2012; Marres, 2013). The development of a "data culture," the emergence of "big" and "small" data, as well as digital metrics, necessitates a reform of sociology education to equip students for the critical understanding and study of contemporary social processes in a digital environment. At this point, attention should also be drawn to public digital sociology (Christopher, 2014: 205–224), which plays a key role in making sociological knowledge accessible to the broader public and fostering social dialogue in online spaces. By utilizing digital media, it enables faster exchange of ideas, greater visibility of sociological discourse, and active citizen participation in understanding social processes. In this context, the reform of sociology education should encourage students to use digital media as a space for learning, exchanging views, and social engagement, thereby developing competencies for active participation in public life and promoting sociological literacy.

The concept of contemporary teaching in the 21st century is in constant flux, strongly influenced by new technologies that are redefining traditional learning models (Prodović Milojković, et al., 2024: 247–262). Within sociology education, AI, with its transformative potential, enables the reshaping of classical teaching methods and the orientation of the educational process toward modernization. Modernization involves integrating intelligent techno-pedagogical knowledge, creating opportunities to combine technological competencies with teachers' pedagogical skills in working with AI. The potential for personalized learning allows educational materials to be adapted to the specific needs and abilities of each student, facilitating the work of teachers and other educational staff, including administrative personnel. This opens the door for the introduction of more contemporary curricula and didactic materials, fostering a more creative and interactive environment for learning sociology. Furthermore, new technologies simplify administrative tasks at all levels, from secondary schools to universities, allowing instructors to devote more time to the quality of teaching and student learning in a digital social context. On the other hand, in education, AI enables personalized lesson plans and tailored resources but can also further marginalize students who lack adequate access to technology (Selwyn, 2019), as previously noted. The open letter "*Pause Giant AI Experiments*" (March 2023)[8], signed by numerous global technology leaders and researchers, including Elon Musk and Steve Wozniak, drew public attention to the risks of uncontrolled AI development (Nikolić and Vučenović, 2024). For these reasons, digital sociology must analyze not only the positive effects but also the potential risks and inequalities accompanying AI implementation, highlighting both the need and opportunity for *reform in sociology education*.

Contemporary research indicates that digital environments, despite offering new opportunities for expressing and re-creating identity, reproduce gender inequalities, double standards, and male dominance (Filipović, 2010: 361–392; Žakelj, 2014: 5–21). At the same time, the emergence of a new pattern of sociality—'networked individualism' (Petrović, 2009: 23–44; Petrović, 2013: 417–438)—demonstrates that traditional organizations are no longer essential for collective action in the digital age, as their functions are increasingly assumed by new communication technologies (Petrović and Petrović, 2017: 405–426). These insights confirm that reforming sociology education is necessary to equip digital sociology with the tools to critically analyze both the potentials and limitations of digital social practices. Regarding methodological approaches (Petrović, 2019), traditional sociological methods—such as surveys, interviews, case studies, and content analysis—still predominate, although in some cases they are applied in digitalized forms (online surveys, interviews via platforms like Skype) or to digital content (website analysis). What is noticeably lacking, however, is the broader application of innovative methodologies, such as the analysis and visualization of digitally generated data. Although such practices remain rare even in more developed sociological communities (Petrović, 2018: 557–582), this very gap highlights the need to systematically integrate digital sociology into curricula. This would educate a new generation of digital sociologists, capable of applying contemporary research techniques, including digital network analysis using tools such as Netvizz and Gephi, and of addressing the new questions posed by digital society to sociology. Only within this context would digital technologies create new opportunities for learning and education, particularly in higher education, where they could provide access to rich information resources and flexible forms of instruction. This underscores the necessity of reforming sociology education to incorporate digital tools and develop digital competencies, thereby adapting the educational process to the demands of contemporary society. All of this is closely aligned with the Strategy for the Development of Artificial Intelligence in the Republic of Serbia for the period 2025–2030, which emphasizes the importance of education both in training AI specialists

[8] See: Future of Life Institute (2023). *Open Letter: Pause Giant AI Experiments*, available at https://futureoflife.org/open-letter/pause-giant-ai-experiments/, accessed 28 July 2024.

and in adapting to the changes AI brings to the learning environment of students (Official Gazette of RS, No. 30/18). In this context, as part of the reform of sociology education, it is necessary to develop the ability for critical analysis of digital processes and their transformative role in society. This involves examining the relationship between technological and social dimensions, understanding the theoretical foundations of digital sociology, assessing the consequences of digitalization and surveillance capitalism, and recognizing the links between the digital divide and social inequalities in both global and national contexts (Davies, 2014, February 25). All of this aims to ensure that education serves as a leading tool for fostering social cohesion, enabling the prevention of social exclusion and inequality (Nesterova, et al., 2019).

A symbolic turning point in public reflection on the ethics of artificial intelligence was marked by Pope Francis's address at the G7 summit in 2024, where he for the first time highlighted the risks of AI development without clearly defined moral boundaries. On that occasion, he called for the adoption of an international agreement to ensure its ethical development and application, warning that "technology devoid of human values—compassion, mercy, morality, and forgiveness—is far too dangerous to develop without limits" (Nikolić and Vučenović, 2024: 11). The experiences of certain countries (e.g., Cuba, Iran, North Korea, China, and Saudi Arabia) demonstrate that digital technologies, including AI, can serve as instruments for content filtering, censorship, and surveillance, further underscoring the necessity of protecting human rights in the digital age.In this context, the reform of digital sociology gains particular importance: it must provide a critical framework for understanding the social consequences of AI in the era of deglobalization and be integrated into contemporary sociology education. Pierre Léna also emphasizes the significance of responsible and thoughtful integration of new technologies into the educational process, highlighting that their effectiveness depends not only on adapting curricula but also on the competence and professional quality of teaching staff (Prlja, et al., 2021).

All of this confirms the need for modern sociology education to develop a critical, ethical, and socially responsible perspective on digital sociology, equipping students to understand and critically reflect on the consequences of technological transformations in contemporary society.

Conclusions

Artificial intelligence (AI) is becoming one of the most influential drivers of contemporary social change (Skopek, 2023; Hagerty and Rubinov, 2019), thereby creating space for the development of digital sociology as a subdiscipline that examines the mutual shaping of technology and social structures in conditions of deglobalization (Prlja, et al., 2021). AI achievements, shaped by interdisciplinary contributions, demonstrate that it transcends the role of a technological tool and becomes an actor influencing the transformation of social relations, identities, and power structures (Castells, 2010; Wajcman, 2017). Literature analysis indicates that the application of AI and digital technologies simultaneously creates opportunities for progress and risks of deepening existing inequalities. Algorithms and digital platforms can either reproduce or mitigate social disparities (Noble, 2018; Van Dijck, 2020), placing digital sociology in the position of developing critical theoretical frameworks, ethical reflection, and methodological innovations (Bojić, 2022: 1040). In this sense, digital sociology must remain interdisciplinary, research-oriented, and socially responsible, integrating insights from sociology, philosophy of technology, educational sciences, and ethics (Edelmann, et al., 2020: 61–81).

The reform of sociology education represents a strategic direction of action. In order to prepare future researchers and students to understand the social consequences of AI, it is essential to incorporate digital competencies, algorithm analysis, critical reflection on digital processes, and ethical perspectives on technology into educational programs (Floridi, 2019; Babić and Matović, 2025, pp. 610–634). This positions education as a key space for developing digital literacy, social responsibility, and the ability to shape a more just digital society (Eubanks, 2014; 2018).

Sociologists face both a challenge and an opportunity: digital sociology can become a framework for the thoughtful socio-technical transformation of society (Selwyn, 2019; UNESCO, 2021; OECD, 2022; Joyce, et al., 2021). Future research should focus on:

1. mapping new forms of digital inequalities and algorithmic discrimination;
2. monitoring the social impacts of AI on different social contexts and vulnerable groups;
3. developing ethical standards and policies for AI application;

4. analyzing educational models that successfully integrate digital sociology into formal education.

Maintaining a balance between technological development and social values will be crucial for the future (Budić, 2022; Prlja, et al., 2021). To remain relevant and transformative, sociology must actively participate in shaping technology policies, critically monitor the implications of AI, and promote the development of socially sustainable digital solutions (Nikolić and Vučenović, 2024; Dewey, 2021; Kozić, 2023).

As Kissinger (Kissinger, et al., 2022) states, "Humans still control the future. We must shape it with our values"—reminding us that the development of AI and digital technologies cannot be left solely to technical or economic forces, but must be guided by social principles and ethics (Harari, 2024). Digital sociology, therefore, is not only a new field of study but also a mission—to ensure that technology contributes to creating an inclusive, just, and humane society in the digital era (Serpa, et al., 2025; Grum and Grum, 2020).

As Kate Crawford, principal researcher at Microsoft Research and founder of the AI Now Institute, explains (Rosenberg, 2017): "Data will always carry traces of its history."

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Conflict of interests

The authors declare no conflict of interest.

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Feedback from Students on Career Opportunities in Tourism: A Cognitive Research Approach

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Abstract: In order to learn different techniques of tourism, students acquire different knowledge and skills, but also develop critical opinions, seek more and more information and knowledge from different perspectives. The demands of the labor market, together with the competences acquired during studies, foster students' critical thinking. Through providing feedback, students' opinions can serve as confirmation of the effectiveness of acquiring empirical and practical knowledge in higher education institutions. The aim of this study is to investigate opinions and expectations of students of Faculty of Hotel Management and Tourism about employment opportunities in the tourism industry, after completing their formal education. The authors conducted a quantitative study analyzing the responses of two groups of students (first-year students and fourth-year students) of the University of Kragujevac, Faculty of Hotel Management and Tourism in Vrnjačka Banja, Serbia. The results indicate that students primarily value employment opportunities in tourism when they involve managerial or leadership positions. Furthermore, while some students express readiness to accept any tourism-related job after graduation, they also advise prospective students to carefully reconsider pursuing higher education in tourism. The results will be very useful for universities (deans, administrators, and other) and future creators of the educational policy of the subject research, but also of wider scope.

Keywords: *Tourism labor market, Students' attitudes, Higher education, Employment, Cognitive perspective.*

Introduction

Higher education and the social relationships of teaching and administrative staff with students can be understood as „calculated instrumental exchanges, whereby, in exchange for the fee they pay, students expect to receive an education designed to ensure they have the knowledge, skills and innovative capabilities required by businesses and the economy in the competitive global market place" (Leach, 2019, p. 155). The key concept of higher education is certainly the creation of employment opportunities and employment is the main expectation that students have from university education (Cheng at al., 2022; Gorgodze et al., 2020; Khan and Hemsley-Brown, 2024). Also, the perception of employment opportunities after graduation is one of the key factors influencing students' satisfaction during their studies, as well as the likelihood that they will recommend their higher education institution to others (Khan and Hemsley-Brown, 2024). Despite all the above, the authors of this study share the opinion of Leach (2019) that higher education is "more than the instrumental 'value for money' meeting of the needs of business and the economy ", as well as that one of its most valuable characteristics is giving purpose and meaning to people "to envisage, plan and manage their career journeys in a complex world of work and contested employment relationships" (Leach, 2019).

The responsibility for ensuring efficient and fair employment after graduation should be shared among key stakeholders—including higher education institutions, students, governments, and employers—and should not be placed solely on the education institution, as is the case in some countries (Cheng at al., 2022). At the same time, understanding the expectations of students by their universities is ex-

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tremely important, especially if higher education institutions want to attract young people and if they strive to create teaching programs in accordance with the demands and expectations of young people and trends in the labor market (Gorgodze et al., 2020). In modern higher education, receiving feedback from students is standard practice for teachers around the world and this feedback can effectively contribute to the design of higher education and teaching policies (Flodén, 2017; Wijesundara, 2015). Many higher education institutions prepare reports on the quality and self-evaluation of the institution (Zou et al., 2012). Such reviews are created as an implication for quality assessment within the activity and focus on students' learning experiences, their achievements and feedback. Therefore, university teachers have the task of balancing all the factors that affect the teaching process, in order to achieve inviting feedback, all with the aim of effective and quality education system.

This paper focuses on feedback from students of the University of Kragujevac, Faculty of Hotel Management and Tourism in Vrnjačka Banja. The Faculty of Hotel Management and Tourism consists of 2 study programs of undergraduate academic studies: study program Hospitality and Tourism and study program Gastronomic Management. The faculty has 724 active students who attend studies in the Serbian language. Furthermore, undergraduate, master's and doctoral academic studies are available to students. The Faculty of Hotel Management and Tourism in Vrnjačka Banja is part of the University of Kragujevac, which is the fourth largest state university in the Republic of Serbia. The reason for choosing the subject institution for the analysis is because it is the only state faculty for tourism in the Republic of Serbia (Faculty of Hotel Management and Tourism in Vrnjačka Banja, 2025). The opinions of first-year students were defined as the experimental group, while the control group was the opinion of 4th-year students. The findings of the research relate to general questions about quality and future employment in tourism, and those related to accepting jobs after graduation and advice to younger generations regarding choosing tourism as a future career are the most important.

The paper is composed of several chapters that follow. First, the study begins with the introductory part of the paper, followed by the theoretical framework of previous findings in the field of cognitive research of students, especially focusing on tourism students. Subsequently, the applied methodology is outlined. The results obtained after an extensive analysis were presented and analyzed through a discussion and a conclusion at the end of the paper.

Theoretical background

Career opportunities in Tourism

Tourism remains one of the world's most important industries and a significant source of employment. In 2024, the travel and tourism sector supported an estimated 357 million jobs, representing approximately 10% of total global employment, or approximately one in ten jobs worldwide (World Travel and Tourism Council, 2024). This number is expected to increase to approximately 449 million jobs by 2034, indicating continued strong growth in the sector and its increasing importance to the global economy (World Travel and Tourism Council, 2024).

The tourism industry is considered one of the main sectors in which human resources and highly qualified professionals with advanced skills play a very important role (Nakipova et al., 2021; Stacey, 2015; Tfaily, 2018; Ganie and Dar, 2020). As a labor-intensive sector, tourism relies heavily on human capital, which makes aspects such as job quality, education, and skills particularly significant (Grobelna and Dolot, 2018). These factors are primarily addressed through education and training, which play a key role in preparing future professionals to meet the dynamic requirements of the industry. Therefore, professional education is highly important for employment process and future career opportunities, in particular taking into account the significant expression of internationalization in this industry (Ladkin, 2006; Chinasa and Ozgit, 2024; Hjalager and Andersen, 2001). In this regard, the employment process in tourism industry begins during higher education, and even earlier (Baum and Szivas 2008).

At the global level, there is a wide range of hospitality and tourism programs that contribute both to graduates' professional development and to the tourism industry as a whole. Ideally, each student is expected to acquire sufficient knowledge and skills to successfully enter the labor market. However, previous research has shown that the reality is often different, with graduates facing significant employment-related challenges (Chuang and Dellmann-Jenkins, 2010). Given that students and recent graduates are at similar life stages, earlier studies have examined their attitudes from the perspective of career advancement expectations, academic adjustment, and professional growth (Schoffstall et al., 2017). Through practical training and direct exposure to real-world job settings, students have developed a variety of impressions about the hospitality and tourism industry—ranging from the potential satisfaction they expect such work to bring, to how they perceive interpersonal relations within these sectors—which in turn influences their motivation to pursue employment in these fields after graduation (Liu et al., 2022).

This makes it particularly relevant to compare the views of students at the beginning of their studies with those in their final years, when they are closer to entering the job market. Earlier research indicates that students tend to be more interested in managerial positions within the tourism industry (Ross, 1993), yet they also tend to remain in the industry only in the short term. This creates a challenge for tourism employers, as the industry faces a persistent problem of knowledge leakage (Bednarska and Olszewski, 2013). Such findings underscore the importance of investigating students' perceptions of their future employment in the tourism sector.

Including Generation Z in the Feedback Process in the Tourism Industry

Involving Generation Z students in providing feedback to high education institutions about their educational experiences and perceptions of the employment and industry can offer valuable insights for aligning academic programs with labor market needs and students' requirements for acquiring knowledge and career advancement (Gormally et al., 2014; Morris et al., 2021; Matejić and Milenković, 2025). This is particularly significant in the Republic of Serbia, where the education system has experienced considerable turbulence in 2025 (Cvetković et al., 2025). For feedback to be truly useful and to help educators improve their teaching, it is essential that those providing feedback possess a certain level of subject knowledge and content understanding. Equally important is the willingness of instructors and institutions to actively seek, interpret, and apply such feedback to better align curricula with industry expectations and enhance students' career readiness (Gormally et al., 2014). Greater attention should also be devoted to providing written feedback, which students perceive as the most useful and valuable part of the learning process (Hyland, 2013).

Exploring the attitudes of Generation Z toward employment in this labor-intensive sector is of growing interest, given that this generation is characterized by high levels of digital literacy and frequent technology use (Grobelna et al., 2023). Based on systematic literature review, Barhate and Dirani (2022) found that intrinsic (careers based on Gen Z's attitudes, self-perception, relationships and motivations) and extrinsic factors (Gen Z's closest environment, family and organizations) determine Gen Z's career aspirations. Also, the authors concluded that Gen Z has "well-defined career expectations and career development plans" (Barhate and Dirani, p. 139). A group of authors (Belle et al., 2022) indicates that the positive mental attitude and development of the individual, i.e. graduating college students, which can be further increased through student practice, prevents the emergence of anxiety related to employment. Leach (2019) makes a controversial contribution to this research field, emphasizing "the flawed assumptions about student expectations, engagement and satisfaction, which fail to acknowledge the positive life-changing impact the higher education experience can have on students and in their work". Additionally, he points out that the processes of understanding students' careers and employment are cognitive and emotional, and that only with the building of a sense of professional identity, employment in the current value system can bring a sense of well-being for the individual (Leach, 2019).

Numerous researches on this topic were also carried out in the tourism sector. Research indicates that Generation Z tends to view the tourism industry through a lens of multiple negative factors, including social constraints, lack of work-life balance, long hours, and heavy workloads. Employment is often described as stressful, exhausting, and seasonal, with low wages that do not ensure a satisfactory standard of living and limited opportunities for career advancement and professional development (Goh and Baum, 2021). At the same time, other studies show that Generation Z students still perceive tourism as an exciting industry that offers opportunities for travel, despite challenges such as dealing with people, long working hours, and potential health and safety issues (Goh and Lee, 2018).

A review of research in China of hospitality and tourism students' career goals and expectations reveals several recurring themes. These include general perceptions of future career success, expectations related to the nature of work, long-term professional objectives, as well as the knowledge and skills that students have—or have not—acquired during their studies (Lu and Adler, 2009).

Many authors examined hospitality and tourism students' perceptions related to employment opportunities before and after completing their studies. Findings vary, but a notable trend suggests that graduates often express more negative attitudes toward employment in the tourism sector than students at the beginning of their studies. For example, Barron and Maxwell (1993) found that first-year students had more positive attitudes toward employment compared to senior undergraduates. Extensive research was presented by Kusluvan and Kusluvan (2000), who explored employment attitudes toward tourism among three groups: high school students in tourism and hospitality, current industry employees, and university students majoring in tourism and hospitality. Building on this, Moyo and Özgit (2022) highlighted differences between students who are early in their studies and those nearing graduation or already employed. Their findings suggest that first-year students tend to be well-informed, highly motivated, and optimistic about working in the tourism industry, whereas final-year students express greater concern about their ability to adapt to real-world challenges. Following this approach, the present study also compares these two groups—those just beginning their tourism education and those completing their studies and actively seeking employment—to better understand how attitudes shift throughout the academic journey.

While existing studies have provided valuable insights into students' attitudes toward careers in tourism, there remains a need for more context-specific research that explores how perceptions evolve during the course of academic study—especially in regions undergoing educational and labor market transitions, such as Serbia. This paper seeks to address this gap by comparing the attitudes and perceptions of first-year and final-year tourism students by applying a cognitive research approach.

Materials and Methods

Sample and Participants

The study involved a total of 137 undergraduate students enrolled at the Department of Hotel Management and Tourism, Faculty of Hotel Management and Tourism in Vrnjačka Banja, Serbia. The sample consisted of 79 first-year students and 58 fourth-year students. Data were collected across two academic years: 2023/2024 (n = 79) and 2024/2025 (n = 58). All first-year participants were enrolled in the course Principles of Tourism and Hospitality, while fourth-year participants attended the Cultural Tourism course. In addition, all students had completed at least one mandatory internship during the academic year in which they participated in the study, ensuring that respondents had some level of practical exposure to the tourism and hospitality industry.

Table 1. *The structure of tourism/hospitality education at Faculty of Hotel Management and Tourism in Vrnjačka Banja*

Level	Study program	Number of students (2024/2025)	Duration	Outcome
Undergraduate level	Hospitality and tourism	451	4 years	Bachelor's Degree
	Gastronomic management	116	4 years	Bachelor's Degree
	Health Tourism	44	4 years	Bachelor's Degree
Postgraduate level	Management in tourism	38	1 years	M.sc. Degree
	Management in the Hospitality hotel industry	30	1 years	M.sc. Degree
	Health Tourism	24	1 years	M.sc. Degree
	Hospitality and tourism	21	3 years	Ph.D. Degree

Data Collection Procedure

During the 2023/2024 academic year, 79 first-year students participated in the study. At the final class of the Principles of Tourism and Hospitality course, students were provided with practical information about the study and informed about the expectations for participation. They were given a period of seven days to complete and return the questionnaire. In the 2024/2025 academic year, 58 fourth-year students participated in the study during the summer semester. These students had completed the majority of their courses, undertaken three internships, or were in the process of completing their final thesis. Similarly, they were given seven days to submit the completed questionnaire. All responses were collected anonymously to ensure confidentiality and encourage honest feedback.

Study Description

For data collection, the authors employed a survey research method, which Goodfellow (2023) describes as significant in the social sciences because "surveys can provide evidence for good practice, knowledge, behaviors, and attitudes." To this end, a semi-structured questionnaire was developed. Although the questionnaire included a large number of items, only a specific subset was used in this study (Paraušić et al., 2025). The questions were adapted and refined based on findings from previous research (Kusluvan and Kusluvan, 2000; El-Houshy, 2014; Sadikoglu and Oktay, 2017). The final version of the questionnaire was created after correcting unclear or ambiguous items. Data were collected by distributing the questionnaire to participants, who were asked to complete it. To facilitate easier collection and processing of responses, the questionnaire was also administered online via Google Forms. The online survey was conducted from November 2023 to May 2025, resulting in a final sample size of 137 students.

Research Question

The central research question of this study is: "Are there differences in perceptions of future employment in tourism sector between two groups of students: experimental (first year students) and control group (fourth year students)". It is anticipated that students during studies will gain deeper insights into career opportunities in tourism, develop more critical and reflective attitudes toward future employment, and better understand both the challenges and advantages of working in the tourism sector.

Variables

To address the research question, two groups of participants were included in the study. The opinions of first-year students were defined as the experimental group, while the fourth-year students served as the control group. A Likert scale was used for assessing respondents' perceptions, with scores ranging from 1 to 5 (1 = strongly disagree; 5 = strongly agree). In addition to the Likert-scale variables, categorical variables were included to examine various factors related to employment and directly assess students' attitudes toward careers in the tourism industry. These variables were selected based on a comprehensive review of the literature, ensuring that they capture relevant aspects of students' expectations, career motivations, and perceptions of industry realities.

Results and Discussions

We used 5 criteria for the research (Table 2) and for each criteria the scale of the number of points was created for each level within each criterion (a typical five-level Likert item, with marks 1-Strongly disagree, 2-Disagree, 3- Neither agree nor disagree, 4-Agree, 5-Strongly agree). Based on all those five criteria, the total number of points for this student research was calculated. Since the total number of points scored by the students for the five criteria mentioned, did not have a normal distribution, the non-parametric Mann-Whitney test was used to compare the results of the experimental (first year students) and control groups (forth year students).

Table 2. *Student results for every criterion in research*

Criteria	Testing group	Students, No.	Medians	Mean rank	Sum of ranks	Mann-Whitney U Test	
						Z	P (2-tailed)
I believe that the drawbacks of working in tourism outweigh the benefits	Experimental	79	3.00	67.19	5308,00	-0.658	0.512
	Control	58	3.00	71.47	4145,00		
I would do any work in the tourism sector	Experimental	79	4.00	74.82	5911,00	-2.060	0.039
	Control	58	3.00	61.07	3542,00		
I would do jobs outside the tourism sector	Experimental	79	2.00	70.79	5592,00	-0.665	0.506
	Control	58	1.00	66.56	3860,00		
I would only take on managerial roles in the tourism sector	Experimental	79	3.00	78.29	6185,00	-3.306	0.010
	Control	58	2.00	56.34	3268,00		
Recommendation for studies in the field of tourism	Experimental	79	2.00	62.66	4950.50	-2.279	0.023
	Control	58	2.00	77.63	4502.50		

The first aspect of the research that was evaluated was "I believe that the drawbacks of working in tourism outweigh the benefits". Looking at Table 1, as the medians of the given characteristics for both groups are equal to 3.00, we can conclude that more than half of the students in both groups had the maximum number of evaluations. Anyway the number evaluation "I believe that the drawbacks of working in tourism outweigh the benefits" is not statistically significantly different for the students of the experimental group and the control group.

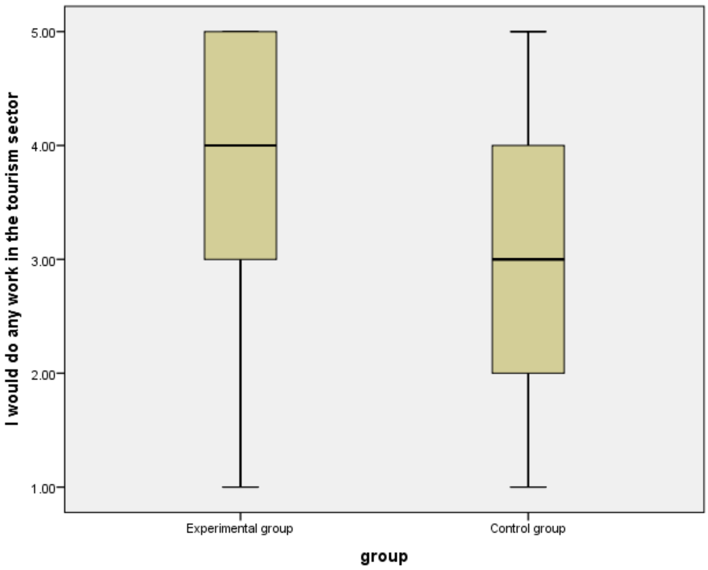

Figure 1. Researh marks evaluation

Another aspect that was valued in research was related to "I would do any work in the tourism sector". With the appropriate statistical analysis, it was established that there statistically significant differences in the answers of students in the control and experimental groups in the case "I would do any work in the tourism sector" (W=-2.060, p=0.039) (see Fig 1. And Table 1.).

There are no significant differences in the students' results regarding the third criterion "I would do jobs outside the tourism sector", (Z=-0.665, p=0.506).

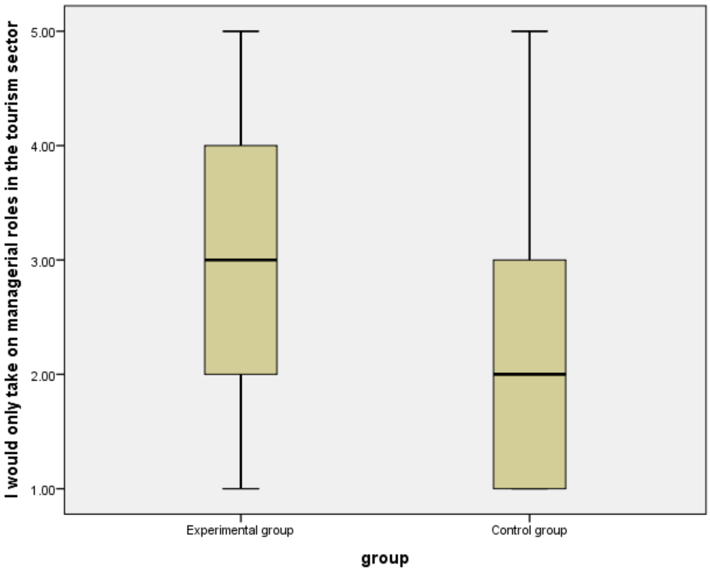

Figure 2. Researh marks evaluation

The next criterion considered during this student research was related to the "I would only take on managerial roles in the tourism sector". The results of the statistical analysis, i.e., the Mann-Whitney test, support the fact that the distribution of the number of evaluations of students in the experimental group and the number of points of students in the control group is statistically significantly different (Z=-3.306, p=0.01) (see Fig 2. and Table 1.). The box-plot (Fig. 2) illustrates differences between the experimental and the control regarding this statement. The median value for first-year students is around 3 (Neither agree nor disagree), while for fourth-year students it is 2 (Disagree). This suggests that younger students tend to be more neutral or moderately agree that managerial positions are imperative (only acceptable options) in the tourism sector, whereas older students are more skeptical of this statement. Moreover, the wider interquartile range in the first-year group indicates greater variability in their responses, while the fourth-year students show a more consistent pattern of disagreement.

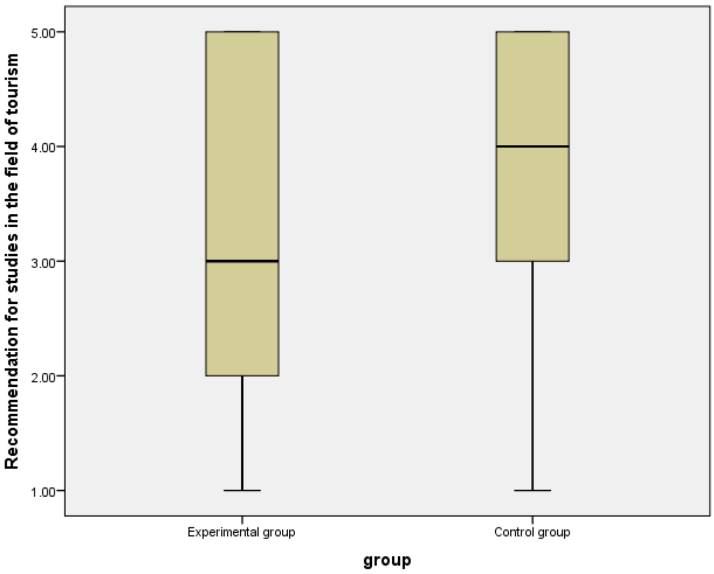

Figure 3. Researh marks evaluation

The last criterion is "Recommendation for studies in the field of tourism". These differences were confirmed with the Mann-Whitney test, so we can conclude that the differences in students' future recommendation is statistically significant (Z=-2.279, p=0.023) in favor of the experimental group (Table1 and Fig 3.). The results, presented in the boxplot, indicate a difference in attitudes between the two groups regarding the statement: "I would strongly recommend studies in the field of tourism." First-year students showed a median response of 4 (neutral), with a wider spread of answers, while fourth-year students had a median of 3 (agree), suggesting a more favorable attitude toward recommending tourism studies. This may imply that with more years of study, students develop a more positive perception of the field. If confirmed by statistical significance, these results point to the importance of academic experience in shaping students' views about the value of tourism education. The difference between the groups was statistically significant ($p < 0.05$), indicating that study level has a measurable influence on students' attitudes.

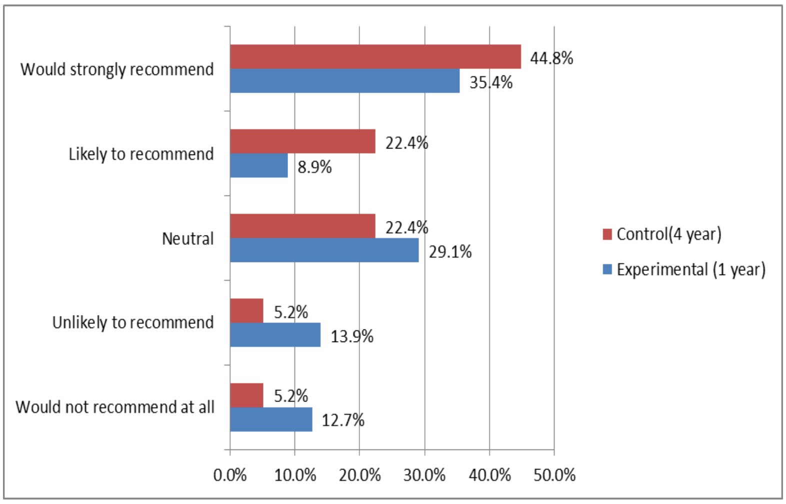

Figure 4. Recommendation for studies in the field of tourism

The distribution of grades in percentages for the variable "Recommendation for studies in the field of tourism" for the control and experimental groups are given in the Figure 4. In addition to the boxplot analysis, a detailed comparison of frequencies for each response level on the Likert scale (Figure 4) provides further insight into differences between first-year (experimental group) and fourth-year students (control group). The data show that 44.8% of fourth-year students stated they would strongly recommend tourism studies, compared to 35.4% of first-year students. Furthermore, 22.4% of fourth-year students selected likely to recommend, whereas only 8.9% of first-year students chose this option. On the other hand, first-year students showed higher percentages in the negative categories: 13.9% were unlikely to recommend and 12.7% would not recommend at all, compared to only 5.2% in both categories among fourth-year students. These findings suggest a clear trend: students with more academic experience in tourism (fourth-year students) are generally more inclined to recommend tourism studies to others, whereas first-year students show more hesitation or uncertainty. This shift may reflect increased familiarity with the field, better understanding of career opportunities, or greater confidence in the quality and relevance of the program.

Conclusions

The Mann–Whitney U test results indicated significant differences between the experimental (first-year) and control (fourth-year) groups regarding students' perceptions of work in tourism. The most pronounced difference was observed for the criterion "Only managerial jobs" ($Z = -3.306$, $p = 0.01$), where first-year students (median = 3) expressed higher agreement compared to fourth-year students (median = 2). This result suggests that as students advance through their studies, they develop a more critical and realistic view of managerial opportunities in the tourism sector. Overall, the findings highlight a transition from more idealistic perceptions among freshmen to a more pragmatic understanding among senior students. Also, fourth-year students have a more favorable attitude toward recommending tourism studies in relation to the group of first-year students (the difference between the groups was statistically significant, $p < 0.05$). This may imply that with more years of study, students develop a more positive perception of the field.

The study was conducted on a relatively limited sample of students from a single higher education institution, which may restrict the generalizability of the results. Future studies should include a larger and more diverse sample, encompassing students from different universities and countries, to enable cross-cultural comparisons.

The results underline the importance of aligning tourism education with labor market realities. Strengthening cooperation between universities and the tourism industry, as well as integrating more experiential learning components, could help bridge the gap between academic expectations and professional realities.

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

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Research Work in the Educational and Cognitive Activities of School Students

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Abstract: The increasing complexity of the modern educational environment requires schools to develop students' ability to independently identify problems, find solutions, and reflect on their own learning experiences. In this context, students' research activities are considered as the most important component of educational and cognitive activities that contribute to personal and intellectual development. The purpose of this study is to substantiate the theoretical foundations and test the model of the organization of scientific research work of schoolchildren at different stages of general secondary education The study used a longitudinal pedagogical experiment conducted in a natural school environment, which involved students in grades 1-11 and teachers involved in the learning process. The research project combines qualitative and quantitative methods, including observations, surveys, diagnostic tests, and expert assessments. The experimental work was carried out in four stages: information-evaluation, fragmentary-technological, sequential-technological and creative-technological. The results show a positive trend in the development of students' research activities at all levels of secondary education, manifested in increased motivation, independence and reflective skills. The presented model has proven its effectiveness in creating conditions for the gradual development of research competence and students' readiness for independent cognitive activity. The results obtained confirm the educational potential of research activities as a means of improving the quality of education and supporting students' self-development.

Keywords: *research work, research activity, structure, components, content and forms, age characteristics of school students, model, stages.*

Introduction

Socio-economic changes in modern society place high demands on graduates for an education system capable of independent decision-making, a creative approach to problem solving and continuous self-development. The rapid growth of information flows makes it difficult for students to navigate knowledge, understand scientific achievements and meaningfully apply what they have learned. In this context, one of the main goals of general secondary education is to develop students' ability to identify problems and find non-standard solutions, which requires a purposeful organization of research activities in the educational process.

In pedagogical theory and practice (Shchukina, 1986), concepts such as research-based learning, research-based teaching methods, and student research activities are widely used. However, these notions are often interpreted inconsistently, which limits their practical effectiveness. At the same time, the predominance of reproductive teaching methods continues to limit the development potential of school education.

Despite the recognition of the importance of research activities, a number of contradictions remain: between the increased demand for research training and insufficient theoretical justification of its educational potential; between teachers' understanding of the need to organize research activities and the lack of methodological (Ukropova, 2023)support for its implementation; and between attempts to introduce research activities at different school stages and the absence of a systematic approach to their organization.

The analysis of existing research (Tyaglova,2003; Slastenin, et all, 2004; Xonnazarova, 2023)

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demonstrates that, although theoretical prerequisites have been created for organizing students' research work, the educational potential of such activities and the principles of their systematic implementation at all levels of school education have not yet been sufficiently studied. In this regard, the subject of this study is defined as research work in the educational and cognitive activities of schoolchildren.

The purpose of the article is to develop the theoretical foundations and experimental substantiation of the model of organizing scientific and research activities of students in the school system.

Theoretical background

The research activity of students is considered as a specific form of educational and cognitive activity aimed at the independent search for subjective new knowledge. Unlike scientific research aimed at achieving new objective results, students' research activities are aimed at developing a research position in relation to the world around them, other people and themselves. In this sense, research activity acts as a universal way of cognizing reality and as a means of personal development in a dynamically changing educational environment.

Theoretical analysis (Obukhov, 2004; Fethiye, 2009; Rahmouni and Aleid, 2020) allows us to interpret research activities not only as a process that contributes to the acquisition of knowledge, but also to the formation of students' experience in identifying problems, building hypotheses, predicting results, analyzing results, and reflecting about their actions. This practice includes cognitive, practical, creative, and communicative components that form the basis of students' individual and personal development.

Functions of Students' Research Activity. In the learning process, research activities perform several interrelated functions that determine their educational potential.

The reflexive function is manifested in students' understanding of acquired experiences, including cognitive, practical, creative, and interpersonal ones. Reflection allows students to evaluate their actions, regulate their behavior and review their previous experiences when they encounter problems. Within the framework of research activities, reflection becomes a mechanism for understanding successes and failures, personal achievements and ways of self-development.

The motivational function determines the nature of students' learning motivation and supports their orientation towards self-development and self-improvement. Research activities increase intrinsic motivation to learn, stimulate intellectual initiative, and stimulate the development of high-level thinking skills. The interaction of cognitive interest and generalized research skills contributes to the sustainable development of motivation and learning effectiveness.

The function of the worldview is related to the formation of a holistic scientific picture of the world and the integration of moral values and principles into the personal experience of students. Through research activities, students move from sensory perception of reality to abstract conceptual thinking, and then to a deeper understanding of social, natural, and cultural phenomena. This function supports the development of stable beliefs, value orientations, and conscious approaches to knowledge.

The cognitive function of research activity (Lamanauskas, et al., 2020; Cao, et al., 2017) is manifested in the independent assimilation of new knowledge, the activation of mental activity, and the updating of existing knowledge. Research activities contribute to the development of cognitive interests, creativity, and critical thinking, allowing students to analyze information, summarize results, and evaluate their significance in personal and educational growth.

The orientation function provides students with the ability to set goals, plan actions, evaluate results, and regulate their activities. By participating (Ramnarain, 2014; Ekici and Erdem, 2020; Kurbanova, 2023) in the research, students develop an understanding of the relationship between goals, available resources, and expected results, which contributes to the formation of self-regulation, responsibility, and readiness for future professional and social life.

The Structure of Research Activities. The structure of students' research activities is understood as an interconnected system of components, the interaction of which ensures the realization of its educational potential (**Alipina, et al.,2025**).

The value-objective component reflects students' motivation to engage in research and their ability to set meaningful goals. This component determines the direction of research actions and the conscious perception of research goals.

The intellectual and creative component characterizes the ability of students to work with information, apply their knowledge, and form new ideas. It manifests itself in the flexibility of thinking, originality of solutions, and the ability to adapt knowledge to new conditions.

The operational component is related to the formation of research skills, including analysis, comparison, generalization, identification of cause-effect relationships, planning of research procedures. These skills enable students to act independently and purposefully in various research contexts.

The assessment component of academic performance is related to the ability of students to assess the conformity of research procedures and results, reflect on their actions and make necessary adjustments. Evaluation and monitoring functions support self-criticism, objectivity and awareness of personal progress.

The interaction of all four components ensures the integrity of the research activity and supports its leading function – reflection. Changing one component affects the development of others and forms a dynamic system aimed at personal and educational growth.

Age-Related Features of Research Activities. The age characteristics of students at various levels of general secondary education determine the content, forms and methods of organizing research activities. Although research activities at all stages contribute to the development of similar personal qualities, the degree of independence, the complexity of tasks, and the scope of application vary depending on the age and level of knowledge of students.

Table 1. Content and Forms of Students' Research Activities at Different Stages of General Secondary Education

Age level	Content of research activities	Form of research activity
Primary school	Topics of students' works are selected from the content of academic subjects or close to them. The problem of a project or research that provides motivation for inclusion in independent work should be in the area of the student's cognitive interests, located in the zone of proximal development. It is advisable to limit the duration of the project or research to 1-2 weeks in the mode of regular and extracurricular classes or 1-2 double lessons. Along with the formation of skills for individual elements of project and research activities, students in traditional classes, starting from the 2nd grade (such as goal setting, question formulation, reflection, action planning, and so on), it is possible to conduct one project or research in the 3rd grade in the 2nd half of the year, and two projects or research in the 4th.	For primary school students, the dominant activity at this stage is a mini-project: a short-term introductory activity within a single subject with direct pedagogical guidance - tasks for developing thinking (within a single field of knowledge), but with a well-thought-out structure and clearly defined goals.
Main secondary school	Topics of children's works are selected from the subject and intersubject content areas, problems are close to understanding and exciting teenagers in terms of personal, social, and collective relationships. The result should be practically significant. In accordance with age specifics, the goals of developing of communication skills come to the fore.	Students of 5-7 grades are involved in practice-oriented activities with direct, but flexible coordination of actions on the part of the teacher - a single project (in related subjects: biology and ecology)
Pre-profile-oriented school	Topics of students' works are selected from the non-subject content area, problems are close to understanding and concern teenagers in terms of personal, social, collective and relationships. The result should be socially and practically significant. It is advisable to present the research results at a school conference. In accordance with age specifics, the goals of developing communication skills come to the fore in the foreground of the teenager.	Students of the pre-profile-oriented stage master the work on an interdisciplinary project, engaging in creative activities. The nature of project coordination on the part of the teacher is implicit, imitating the project participant.
Profile-oriented school	Topics and problems of project and research work are selected in accordance with the personal preferences of each student and should be in the area of their self-determination. The formation of an appropriate level of research activity (i.e. independent practical knowledge of research technology) should be completed by the end of the 10th grade. In high secondary school, it is advisable to perform work on the basis of profile-oriented scientific institutions, universities with the involvement of specialists.	For senior school students, research work becomes relevant. The teacher provides educational assistance in the form of support. Individual or mini-group forms of work are preferred. Wide use of various forms of project and research activities is promising: expeditions, conferences.

At the initial level, research activities are closely related to the content of the discipline and are characterized by short-term projects carried out under the guidance of a teacher. In junior high school, research tasks become practice-oriented and interdisciplinary, with an emphasis on communication and collaboration (Tukiyo et al., 2024; Kong, 2025). At the pre-professional and profile-oriented stages, research activity acquires greater independence, social significance, and professional orientation, culminating in the preparation of students for independent research work.

The age-related features of students` research activities are summarized in Table 1.

Thus, research activity serves as a systemic educational phenomenon that combines the cognitive, motivational, value-oriented and operational aspects of students and underlies their self-realization and lifelong learning.

Methods and Materials

The study used a longitudinal pedagogical experiment conducted in the context of natural education in the general secondary education system. The design of the study is aimed at substantiating and verifying the model of organizing research work of students at various stages of school education, combining theoretical analysis with empirical methods. The experiment was conducted for three years and included successive stages reflecting the gradual development of the students' research activities.

The study participants were students in grades 1-11 and teachers involved in the learning process. The study covered all levels of general secondary education: primary, incomplete secondary, pre-professional and specialized. Teachers working in the respective classrooms acted as specialists in diagnostic procedures. Based on a sequence of expert assessments, a representative sample of students was developed.

The experimental work was organized into four interrelated stages:

1. **Information and Evaluation Stage** – aimed at identifying the current state of research activities in the school system, understanding its role by the participants, and the desire to implement it.
2. **Fragmentary-Technological Stage** – aimed at structuring existing elements of research activities into a single system and developing partially search and research skills.
3. **Sequental-Technological Stage** – aimed at forming students' readiness for independent research work through the systematic introduction of a research approach in teaching.
4. **Creative-Technological Stage** – aimed at the creative application and improvement of research technologies, as well as increasing the independence and self-regulation of students in research activities.

To ensure the reliability and validity of the results, a set of qualitative and quantitative methods was used:

- pedagogical observation;
- questionnaires for teachers, students, and parents;
- conversation and interview;
- analysis of school documentation;
- standardized diagnostic methods, including tests measuring motivation, rationality, cognitive needs, and emotional-volitional characteristics;
- graphical tests aimed at identifying students' needs for activity and self-regulation.

The diagnosis of students' research activities was carried out on the basis of a system of criteria and indicators corresponding to the structural components of research activities: value-oriented, intellectual-creative, operational and performance assessment. The diagnostic complex included an expert assessment, psychological and pedagogical tests, and repeated observations conducted at the beginning and at the end of the experimental work.

The diagnose the improvement of students` research activities, we have identified the following criteria and indicators (table 2)

Table 2. *Criteria and Indicators for Assessing Students' Research Activity*

Component	Criteria	Indicator
Target	Motive	Interest in the problem
		Interest in practical benefits
		Interest in social benefits
	Need	Attending meetings of the scientific society of students
		Freedom of choice
		Problem pushing
	Skill	Construction of an oral report (message) on the work done
		Finding information
		Structuring of information
Intellectual and creative	Academic performance	Organization of the workplace, selection of the necessary equipment, algorithm
		Introspection
		Quality of knowledge
	Flexibility	Putting forward an idea (brainstorming)
		Finding a compromise
		Interact within a group
	Validity	Availability of the research model and its level of stability
		Awareness of the significance of objective regularities
		Stable, conscious attitude to the material being studied
Performance and evaluation	The level of claims	Objectivity and adequacy of evaluation of research results
	Self-criticism	Formation of ideological ideals in the form of «Self-image» as an individual model
		The desire to defend own conclusions
		Giving objective patterns of personal meanings
		Availability of knowledge about the mechanisms of individual influence aimed at transforming the surrounding reality
		Methodological knowledge of the world
	Self-government	Adaptive manifestations (variability of behavior depending on the situation)
		Ability to exercise self-control and self-regulation
		Striving for recognition of own significance
Operational	Independence	Setting research objectives
		Formulation of the problem, the setting of the hypotheses
		The understanding of the results
	Constructiveness	Sociability
		Find consensus
		Ability to listen and understand others
	Prognostication	Formulation of an assumption (hypothesis)
		Question statement (search for a hypothesis)
		Planning of the activities

The diagnostic tools applied at different stages of the study are shown in Table 3.**Table 3.***Diagnostic Tools Used to Identify Levels of Students' Research Activity*

Research activity component	Diagnostics
Value-purpose approach	Observation
	Analysis of school documents
	Graphic test "Determining the need for activity"
	Lusher's Test
Intellectual-creative	Observation
	Method "Measurement of rationality"
	The method of "Diagnostics of social and psychological installations of the personality in motivational-requirement sphere."
	Conversation
Operational	Observation
	Method "Motivation for success and fear of failure"
	Method of "Dimension of rationality"
	Conversation
Performance and evaluation	Observation
	Method "Motivation for success and fear of failure"
	Graphic test "Determining the need for activity"
	Conversation

The collected data was processed using comparative analysis, which made it possible to identify changes in the levels of research activity of students at different stages of school education. Quantitative indicators were analyzed in dynamics, and qualitative data were interpreted to identify trends in the development of motivation, independence, and reflective skills.

Results

The experimental study was conducted at all levels of general secondary education for three years. The results show changes in the levels of students' research activity, identified by diagnostic procedures used at the beginning and at the end of the experiment.

At the initial stage, the diagnosis revealed the predominance of a low level of research work among students of all levels of education. In primary school, 81% of students showed a low level of research, 13% - average, 6%-high. Among students in grades 5-7, low levels were observed in 66% of cases, while 16% demonstrated average and 18% demonstrated high levels. In profile-oriented classes, 42% of students were low, 28% were average, and 30% were high. In the profile-oriented classes, 25% of students showed a low level of research work, 32%-average, 43% - high.

After the implementation of the phased model of the organization of research activities, positive quantitative changes were recorded. In primary schools, the proportion of students with low research activity decreased to 76%, while the average level rose to 18%; the proportion of students with higher academic achievement remained stable at 6%. The share of low-level indicators decreased to 46% among students in grades 5-7, the average level increased to 36%, and the stability of the high level increased to 18%. In the preliminary profile estimates, the low-level indicators decreased to 22%, while the medium and high levels increased to 38% and 40%, respectively. In specialized classes, the proportion of low-level students decreased to 10%, while the average level increased to 40%, and the high level remained at 40%; an additional group of students (10%) showed an excellent level of research work.

The dynamics of changes in students' research activity levels before and after the experiment are illustrated in Figure 1.

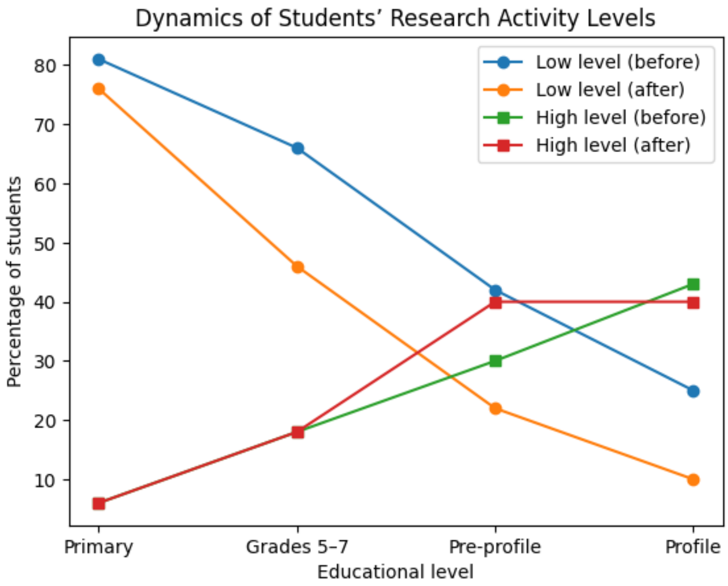

Figure 1. Dynamics of students' research activity levels before and after the experiment

Diagnostics based on the structural components of research activity-value-purpose, intellectual-creative, operational, and performance-evaluation-indicated consistent positive changes in motivation, independence, reflexive abilities, and research skills in all age groups. Monitoring, expert assessment and standardized diagnostic tools have confirmed the reliability of the recorded dynamics.

The results obtained indicate the effectiveness of the proposed model in ensuring the gradual development of students' research activities and increasing their readiness for independent educational and cognitive activities at various stages of general secondary education.

Discussion

The results obtained during the longitudinal pedagogical experiment confirm the effectiveness of the step-by-step model of organizing students' research work in the general secondary education system. The positive dynamics observed at all levels of education indicates that research activities with systematic integration into the educational process can function as a sustainable mechanism for the development of cognitive independence, motivation and reflective abilities of students.

The decrease in the proportion of students with low research activity and, consequently, an increase in the average and high levels show that the gradual complication of research tasks plays a crucial role in the formation of research competencies. The results of this study are consistent with modern research showing the importance of students' independent and search-oriented activities for the development of their cognitive activity, reflexive skills and learning independence. Recent research highlights that structured research tasks are gradually combined with supports, contributing to students' willingness to learn independently and solve problems in various educational contexts (Uiterwijk-Luijk, et al., 2019; Hmelo-Silver, et al., 2007). In particular, data from multilingual educational institutions show that independent and scientifically based learning activities enhance students' ability to work with complex content and promote the development of higher-level thinking skills (Junussova et al., 2024). These results confirm the idea that research activities serve as an effective mechanism for academic and personal development when they are systematically organized and adapted to the age characteristics of students.

The effectiveness of the proposed model can be explained by its correspondence to the age characteristics and developmental needs of students. At the initial level, structural and managerial research tasks supported the formation of skills and motivation for initial research. The introduction of partial search and interdisciplinary tasks in the lower middle and pre-professional periods contributed to the development of communication skills, independence, and responsibility. The increased independence of students during the profile-oriented period and the participation of external experts contributed to the transition to more advanced types of research activities and professional self-determination.

The results also indicate the role of students' research activities in strengthening their motivation to learn and their orientation towards self-development. Improving the skills of reflexive and self-regulation indicates that research activities contribute not only to academic results, but also to the formation of broader personal qualities necessary for successful adaptation in a rapidly changing social and educational environment (Amri and Ekaningsih, 2018).

Despite the positive results, several limitations of the study should be recognized. The study was conducted in a specific educational context, which may limit the generalization of the results. Thus, Qatar's reliance on expert assessments and observation methods, while justified by research objectives, may introduce a degree of subjectivity. Future research may expand the sample size, cover multiple areas, and use additional digital tools to further validate the proposed model.

In general, the discussion of the conclusions indicates that the systematic organization of students' research activities, based on a well-defined theoretical basis and carried out through successive stages, is an effective way to increase the educational and developmental potential of the educational process at school.

Conclusion

The purpose of this study was to substantiate the theoretical foundations and test the model of organizing students' research activities in the general secondary education system. The results confirm that students' research activities serve as an integral component of educational and cognitive activities that promote the development of cognitive independence, creativity, reflection and motivation to learn.

The study shows that the educational potential of research activities is realized through the interaction of motivational, cognitive, ideological, reflexive, and orientation mechanisms that support the personal and intellectual development of students. The proposed model, implemented in successive stages, creates conditions for the gradual formation of research competencies and the willingness of students to independently solve problems at various levels of school education.

The practical significance of the research lies in the possibility of applying a model developed to improve the effectiveness of the educational process in general education schools. The systematic organization of research activities and the gradual complication of research tasks contribute to improving the effectiveness of education and prepare students to solve complex, non-standard educational and life situations. Future research may focus on expanding the empirical base and adapting the model to different educational contexts.

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, *J.S.*; methodology, *Zh.K.*; software, *J.R.*; formal analysis *J.S.* and *Zh.K.*; writing-original draft preparation *A.D.*; writing-review and editing, *J.S.*, *Zh.K.*, *A.D.*; Data curation *A.D.*; Formal analysis *J.S.* and *A.D.*; Funding acquisition *J.S.* and *Zh.K.*; Investigation *J.R.* and *M.A.*; Project adminis-tration *Zh.K.* and *J.R.*; Resources *M.A.*; Supervision *Zh.K.*, *A.D.* and *M.A.*; Validation *J.S.*; Visualization *J.R.*

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Data Availability Statement

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

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Ethical, Legal and Security Aspects of the Use of Artificial Intelligence in Education

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Abstract: The application of artificial intelligence in education and scientific research offers significant opportunities for enhancing learning personalization, analytics, and the efficiency of research processes, while simultaneously raising complex ethical and legal issues. This paper examines the ethical and legal aspects of the use of artificial intelligence in teaching, assessment, and scientific research, with particular attention to the fairness of algorithmic decision-making, system transparency and explainability, data protection and privacy, academic integrity, and the preservation of human responsibility. The paper highlights the risks associated with automated assessment and the potential erosion of teachers' professional autonomy, as well as methodological challenges related to the use of artificial intelligence in research, including bias, verifiability of results, authorship, and mandatory disclosure of AI use. It concludes that sustainable and ethically justified implementation of artificial intelligence requires a human-in-the-loop approach, clear institutional policies, transparent documentation, and continuous oversight, in order to align technological innovation with the fundamental values of education and science.
Keywords: *artificial intelligence, ethics, education, scientific research, privacy, responsibility.*

Introduction

Artificial intelligence (AI)-based technologies are a major force behind pedagogical innovation in the modern educational setting. These technologies range from adaptive systems and personalized learning to automated assessment and data analytics that allow for in-depth tracking of student performance and learning. But this transformational potential comes with complicated legal and ethical issues that call for a methodical, interdisciplinary approach (Dašić et al., 2024b). The ethical aspects of algorithmic fairness, transparency, system explainability, teacher and student autonomy, and academic integrity are therefore given special attention in this paper, along with the legal framework, which includes data protection and privacy, liability, copyright, and the special protection of children and vulnerable groups (Holmes et al., 2021; Nguyen et al., 2023; Colonna, 2023).

There are many prospects for artificial intelligence in education: automated systems can free up teachers' time for pedagogical creativity, while intelligent tutoring and adaptive learning systems can better meet the unique needs of students (Chan, 2023). But, as Nguyen et al. (2023) point out, the drive for creative AI applications also necessitates that, in the lack of sufficient protections and regulations, fundamental rights, moral values, and educational autonomy not be jeopardized. In actuality, this means that it is necessary to proactively assess how AI systems used in educational institutions affect instructors, students, parents, and other stakeholders (Rousi, Alanen, Wilson, 2022).

The use of artificial intelligence presents a number of ethical concerns, such as those pertaining to accountability, transparency, and the defense of fundamental rights (Stanković et al., 2024). Important

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concepts such algorithmic fairness and non-discrimination, privacy and data security, explainability and accountability in AI-driven decision-making, and the maintenance of autonomy in teaching and learning processes are highlighted in the literature (Holmes et al., 2021; Taddeo et al., 2024). For instance, Colonna (2023) contends that potential and hazards must be carefully balanced and highlights the necessity of a global consensus on ethical norms for AI in education. In addition, automated assessment systems raise questions about whether teachers remain “in the loop” and whether legal requirements—such as those set out in Article 22 of the General Data Protection Regulation (GDPR)—are adequately met.

Legally speaking, the use of AI in education necessitates regulation in a number of areas, such as the processing of student and teacher data, protections against discrimination or unjustified profiling, the distribution of liability for mistakes or harm caused by AI use, and issues of authorship and rights pertaining to AI-generated content (Ismail, Aloshi, 2023). While Colonna (2023) emphasizes Article 22 of the GDPR as a basis for the legal and ethical oversight of automated decision-making systems, Holmes et al. (2021) state that educational uses of AI systems must be in line with the ethical ideals of “respect, fairness, and transparency.Furthermore, some authors point out that the introduction of generative AI into educational processes is particularly sensitive from the perspective of privacy rights, content ownership, and responsibility for outcomes (García-López, Trujillo-Liñán, 2025).

Secondary and higher education institutions must approach the use of AI in the educational setting through institutional governance mechanisms that guarantee the protection of students’ and teachers’ fundamental rights, particularly with regard to privacy and data processing, and establish clear accountability for the use of AI systems in learning support and decision-making. This includes the creation of oversight procedures and ongoing monitoring of system performance (accuracy, bias, unintended consequences), the obligations of transparency (e.g., what data are collected, for what purposes, who has access, and how results are interpreted), and the participation of pertinent stakeholders (students, teachers, administrators) in the creation and execution of usage policies. Such an approach aligns with the literature on ethical and privacy principles in learning analytics and digital educational systems, which emphasizes that legitimate and sustainable deployment of analytics and AI solutions requires transparent practices, institutional responsibility, and clear data protection frameworks (Pardo, Siemens, 2014; Slade, Prinsloo, 2013; Ifenthaler, Schumacher, 2016).

Therefore, a “human-in-the-loop” strategy is advised since it guarantees that AI systems do not function as opaque “black boxes” and promotes teacher autonomy in monitoring and interfering in them (Colonna, 2023). This is especially crucial when it comes to academic integrity, since AI technologies have the potential to be both helpful and harmful (Rousi et al., 2024; Huang, 2023).

This analysis focuses on the ethical and legal aspects of AI usage in secondary and higher education while taking into account the larger social and institutional environment, given the complexity and quick speed of AI adoption in educational systems (Vuković et al., 2025; Lunić, Òesarević, 2025). Within this framework, the article looks at potential value conflicts, the consequences for current legal and regulatory frameworks, and the main opportunities and problems that AI presents to educational practice. As an example of the multidisciplinary character of these challenges, special attention is given to the application of AI in scientific research, legal elements of data protection, copyright, and liability, and ethical issues in teaching and evaluation. In line with contemporary approaches to responsible AI development and deployment, the paper emphasizes the need for governance models that incorporate the human-in-the-loop principle, fundamental rights impact assessments, regular oversight and algorithmic audits, transparent documentation of data sources and processing methods, and the active involvement of relevant stakeholders, including teachers, students, parents, and technical services (Floridi et al., 2018). This paper adopts a structured narrative review approach, primarily drawing on peer-reviewed literature indexed in Web of Science and Scopus, complemented by relevant policy documents, editorial guidelines, and selected authoritative sources outside these databases. The aim is to synthesize ethical, legal, and methodological challenges associated with the use of artificial intelligence in secondary and higher education, as well as in scientific research. The analysis focuses on normative issues rather than technical system performance, with particular attention to accountability, transparency, and human responsibility.

Ethical Issues in the Application of AI in Teaching and Assessment

The biggest IT businesses in the world have started an unprecedented investment wave to maintain competitive advantage and construct the infrastructure required for the AI revolution as the global AI boom continues. It is anticipated that Meta, Alphabet, Amazon, and Microsoft will invest between USD 350 and 400 billion in capital projects this year alone, with the majority going toward building AI data centers—the foundation of all AI applications. This amount of investment is more than twice as much as it was just two years ago, and experts say the "AI arms race," which is becoming more and more popular, is far from over (Richter, 2025).

The worldwide AI market was estimated to be worth around USD 260 billion in 2025 and is expected to expand to over USD 1.2 trillion by 2030, a fourfold increase, according to estimations released by Statista Market Insights in October. This projected rise makes it evident that artificial intelligence is becoming more and more integrated into a variety of businesses, thanks to advancements in algorithms, infrastructure development, and consistent, substantial investment in R&D.

The two biggest segments of the AI market are machine learning and natural language processing (the interaction of computers and human language), as seen in Figure 1. When taken as a whole, they make up over half of the market value and are predicted to continue to be significant until 2030. Furthermore, computer vision, AI robots, and natural language processing are thought to be the most dynamic fields; during the next five years, all three are expected to develop more quickly than the industry average. These industries are anticipated to grow significantly due to the growing use of AI solutions in consumer, healthcare, and corporate markets.

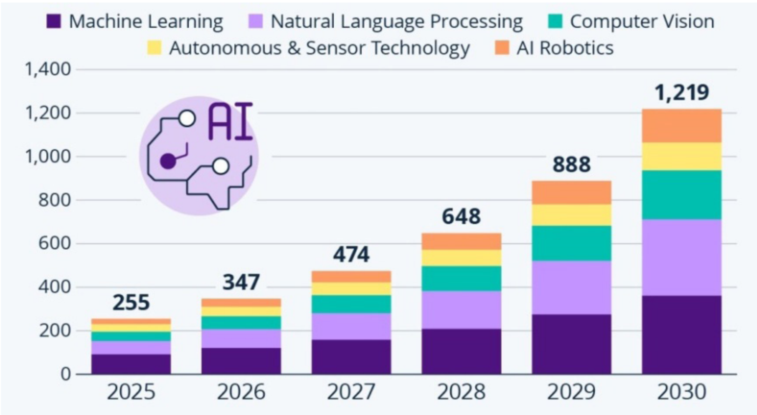

Figure 1. *AI Market Projected to More Than Qaudruple by 2030*

Source: Gaudiaut, T. (2025)

Artificial intelligence's implementation in educational institutions has been further expedited by global investments made by governments and tech businesses, especially in the fields of learning analytics, instructional customisation, and automated assessment. However, ethical considerations become crucial in the areas of teaching and evaluation, when choices are made that have long-term effects on students' academic and career paths (Dašić, 2024a). According to academic research, the use of AI in education is a complicated normative and pedagogical challenge rather than just a technological or organizational issue. (Zawacki-Richter, et al., 2019).

The fairness of algorithmic systems used to support instructional and evaluative choices is one of the main ethical concerns. According to empirical studies, machine-learning-based systems that are trained on biased data or whose results are used carelessly in practice have the potential to replicate or even exacerbate current social and educational disparities (Baker, Hawn, 2022). Such prejudice may lead to the systematic adverse treatment of specific student groups in the context of assessment, undermining the idea of equal educational opportunity. From a technical and ethical standpoint, fairness in educational AI systems should therefore be assessed through a combination of pre-deployment bias audits, subgroup performance analysis, and post-deployment monitoring, as recommended in recent AI governance literature.

The use of automated assessment of written work is particularly problematic, as algorithms are tasked with evaluating the quality of argumentation, structure, or the use of evidence. Studies indicate that different models may produce divergent evaluations depending on linguistic style or the socio-cultural characteristics of authors, raising serious concerns regarding the validity and ethical justification of such systems (Litman, et al., 2021). For this reason, fairness must be an explicit dimension of AI system evaluation prior to their institutional deployment.

Another important ethical issue relates to the transparency and explainability of algorithmic decisions. In many educational contexts, teachers and students lack clear insight into the criteria on which systems base their recommendations or evaluations, which hinders critical assessment and the ability to challenge outcomes. A lack of transparency can erode trust in assessment systems and weaken the legitimacy of educational institutions.

The concept of explainable artificial intelligence (XAI) in education has emerged precisely in response to these challenges. Khosravi, et al. (2022) emphasize that explanations of algorithmic decisions must be tailored to different educational stakeholders—teachers, students, and administrators—in order to possess genuine pedagogical and ethical value. In this sense, explainability is not merely a technical feature of a system, but a normative requirement linked to accountability and fairness.

Concerns about accountability and the professional autonomy of educators constitute a third ethical facet. Teachers' roles as important pedagogical actors may be diminished by an over-reliance on algorithmic recommendations in instruction and evaluation, which could depersonalize the learning process. According to research, there is a chance that technical system outputs will take the place of expert judgment, hiding accountability for educational results (Zawacki-Richter, et al., 2019). In order for the use of artificial intelligence to be ethically justified, final assessment choices must stay within the purview of human accountability and have well-defined opportunities for intervention, correction, and justification. Instead of taking the place of teachers' pedagogical judgment, AI systems should be used as support tools.

The veracity of what AI systems measure and assess is another important ethical issue. Complex learning processes, such critical thinking, creativity, and reflection, run the risk of being reduced to readily quantifiable metrics that fall short of fully capturing the range of educational goals. Williamson and Eynon (2020) caution that technology advancements in artificial intelligence for education frequently come before explicit pedagogical goals are articulated. This can cause a normative shift from what is beneficial to education to what is technically possible.

Beyond technical challenges related to algorithmic bias and limited transparency, contemporary literature clearly indicates that the application of artificial intelligence in teaching and assessment raises broader ethical issues that transcend individual system deployments. Because automated systems can not only influence assessment results but also redefine power dynamics in classrooms and between teachers and students, ethics in AI for education necessitates careful consideration of how technology affects the rights and autonomy of all participants in the educational process. How to guarantee that AI-assisted decisions stay in line with the values of justice, accountability, and pedagogical validity is a crucial ethical question in this context, especially since automated systems may unintentionally marginalize particular student groups or jeopardize teachers' professional autonomy if technology is seen as a neutral or superior arbiter. Additionally, the literature highlights that institutional AI implementation must be accompanied by suitable mechanisms for oversight, evaluation, and value-based deliberation because algorithmic advancements alone are insufficient to address the ethical and social conflicts that emerge in educational settings. This suggests that in order to safeguard educational objectives and fundamental values, systemic concerns—such as open communication among all stakeholders, participatory decision-making, and ongoing monitoring of AI impacts—must be incorporated into the design and assessment of AI solutions (Fu, Weng, 2024; Gouseti, et al., 2025).

For these reasons, rather than relying only on statistical measures of correctness or efficiency, artificial intelligence systems employed in teaching and evaluation must be regularly reviewed in connection to pedagogical aims and values. The aforementioned research leads to the conclusion that ethical concerns with the use of AI in instruction and evaluation are structural rather than incidental. The development, application, and assessment of AI systems in education must incorporate fairness, transparency, human responsibility, and pedagogical validity. Without such a strategy, there is a genuine risk that, in spite of large investments and great expectations, technological advancements could exacerbate already-existing disparities and threaten the core principles of education (Baker, Hawn, 2022; Williamson, Eynon, 2020).

The Use of Artificial Intelligence in Scientific Research

The impact of artificial intelligence has become more apparent in scientific research practice under conditions of significant worldwide investment, from problem formulation and literature search to data processing and model development to manuscript writing, authorship management, and editorial decision-making. However, discussions of AI's use must concurrently address ethics, methodology, technology, and the governance of research practices, with clearly defined human responsibility and verifiability of scientific claims, because AI is becoming more and more integrated into important phases of the research process (Resnik, Hosseini, 2025).

In reality, AI multiplies productivity at several stages of the research cycle: it speeds up the mapping of concepts and important publications, helps organize research questions and hypotheses, automates certain steps in the analytical workflow (like scripting and data cleaning), aids in the interpretation of results, and harmonizes the language and style of manuscripts. Although these applications can boost output, they also raise the possibility of "illusory accuracy," in which AI systems provide credible but false or unsubstantiated claims. Strict verification and documentation of research procedures are therefore required, especially when AI is utilized to create or modify manuscript material (Rentier, 2024).

When AI is used for modeling and inference, particularly when predictive models are used (e.g., in medical, social sciences, economics, and sports sciences), the most significant methodological problem emerges. In order to guarantee verifiability and reproducibility of findings, current standards for transparent reporting emphasize that studies creating or validating models must explicitly describe data sources, predictors, outcomes, processing procedures, validation methods, performance metrics, and limitations (Collins, et al., 2024). The PROBAST+AI framework offers an updated tool for assessing risk of bias and applicability in prediction models using regression and/or AI methods, strengthening methodological control over AI-driven conclusions. However, assessments of quality and risk of bias must not be improvised (Moons et al., 2025).

The implication for scientific research practice is clear: when AI participates in the analytical core of a study, reporting standards and bias-assessment tools should constitute mandatory components of the methodological framework (Collins, et al., 2024; Moons et al., 2025).

The use of AI in research raises ethical concerns that are especially delicate when it comes to authorship, accountability, and contribution attribution. The traditional authorship model is frequently insufficient in modern collaborative research to appropriately reflect responsibility for particular study components; as a result, contributorship-based approaches are becoming more and more important, particularly when portions of the work are produced with the aid of AI tools (Vasilevsky, et al., 2021).

In practice, this means that research teams should define in advance: (a) where AI is used (e.g., search, coding, analysis, writing), (b) who is responsible for verifying AI outputs, and (c) how these contributions are documented in the manuscript and internal project records. Normatively, AI cannot assume responsibility for the truthfulness or integrity of scientific work; responsibility remains with human authors and institutions (Vasilevsky, et al., 2021).

AI-related editorial and publishing practices have changed quickly in recent years, yet there are still significant variations within disciplines. Guidelines for imaging and medical journals underline the need for humans to maintain complete control over content and the secrecy of the peer-review process, forbid listing AI as an author, and require editors to be transparent (Moy, 2023). According to norms in biomedical publication, authors must proofread and verify information, maintain accountability for correctness, and fully declare the use of generative AI, even when it may be employed to increase readability (Lubowitz, 2024).

At the level of broader ethical frameworks, Resnik and Hosseini (2025) propose a differentiated approach to disclosure: when AI use may affect interpretation or reliability, or when it constitutes a deliberate and substantive component of the work, disclosure should be mandatory; in other cases, it may be optional or unnecessary, provided that criteria are clearly articulated and justified. Disclosure of AI use should be considered mandatory whenever AI systems contribute to data analysis, model development, or interpretation of results, whereas optional disclosure may be acceptable when AI is used solely for language editing without influencing scientific claims.

Based on recent research (Vasilevsky, et al., 2021; Rentier, 2024; Resnik, Hosseini, 2025), a cogent framework that prioritizes a clear comprehension and documentation of AI's role within the research process can operationalize the responsible use of AI in scientific research. In order to enable transparency of research processes and facilitate later evaluation, this involves methodically mapping the ways, stages, and goals for which AI is employed throughout a research project. The identification and mitigation of bias hazards presented by automated systems, as well as the transparent reporting of AI use in data analysis, modeling, and inference, require specific attention. In this context, the significance of verification and auditability is highlighted, including the need for human review of important research decisions and outcomes as well as the preservation of pertinent research traces, such as information on tools used, their versions, input and output data, and applied parameters and procedures. However, in order to maintain both individual and group accountability for scientific findings, ethical AI use necessitates a well defined distribution of duties and responsibilities within research teams, especially for components developed with automated aid. Lastly, the literature emphasizes the necessity of proportionate and consistent disclosure of AI use, to the extent that it is pertinent for evaluating research integrity, reproducibility, and dependability using criteria that are verifiable, justified, and properly described.

When used as a tool to supplement human competence rather than take the place of methodological responsibility, artificial intelligence can provide real advantages for scientific research. Four fundamental requirements have been identified by recent literature: appropriate, consistent disclosure, unambiguous distribution of contributions and responsibilities, assessment of bias risk, and transparent reporting. If this isn't done, there is a risk of systemic degradation of verifiability and trust in the scientific method rather than just isolated errors (Collins, et al., 2024; Moons et al., 2025; Resnik, Hosseini, 2025).

It is also crucial to stress that integrating AI into more general open and reproducible science procedures is essential to the long-term viability of its usage in scientific research. As automation of analysis, code generation, and text production may impede subsequent verification unless clear standards for sharing data, models, and procedures are established, modern scholars observe that AI-assisted research workflows can worsen already-existing reproducibility issues. In this way, it is both an ethical and an epistemological need of contemporary science to insist on the transparency of methodological procedures, the availability of analytical products, and the explicit documenting of judgments supported by AI. However, the literature warns that generative and predictive systems can only greatly speed up scientific discovery if they foster critical thinking rather than acting as stand-ins for human judgment or masking ambiguity in data and models. In order to maintain confidence in scientific knowledge in a setting where artificial intelligence has become an essential component of research infrastructure, more focus is being placed on creating research cultures that integrate technological innovation with standards of transparency, accountability, and group quality control (Haibe-Kains, et al., 2020; van Dis, et al., 2023).

Conclusion

The examination of ethical concerns in the use of AI in scientific research and in teaching and assessment shows that modern educational and research systems are going through a phase of significant technological change that goes beyond the simple addition of new tools. Artificial intelligence is progressively becoming a structural element of decision-making processes, ranging from designing research investigations, analyzing data, and producing scientific information to evaluating students' knowledge and progress. Because of this, the issue of AI deployment necessitates normative, methodological, and institutional consideration rather than merely focusing on technical efficiency.

The investigation has revealed that the fairness of algorithmic decisions, system transparency and explainability, the protection of instructors' professional autonomy, and the validity of pedagogical assessments are important ethical issues in the field of teaching and assessment. Although automated and semi-automated systems can increase efficiency and consistency, they also run the risk of perpetuating current disparities, simplifying difficult educational objectives into readily quantifiable metrics, and eroding confidence in knowledge assessment procedures. As a result, rather than taking the place of human pedagogical judgment, artificial intelligence in education must continue to be a supporting tool.

Artificial intelligence, on the other hand, has become a potent productivity and analytical capacity accelerator in scientific research, allowing for quicker processing of massive datasets, more complex models, and more effective administration of research workflows. These advantages come with higher expectations for methodological rigor, open reporting, and responsibility allocation, though. Particular emphasis is placed on the necessity of precisely defining the role of AI in research, applying standards for evaluating the risk of bias, and establishing clear guidelines regarding authorship, contribution, and required disclosure of AI use—where such use may affect interpretation and trust in findings.

A broad conclusion can be reached by combining the two areas of analysis: ethical concerns about the use of AI in science and education cannot be resolved piecemeal; rather, they must be viewed as a component of a cohesive framework of responsible knowledge governance. Regardless of the level of automation, human actors—teachers, researchers, editors, and institutions—must retain ultimate accountability for educational and scientific judgments. This is what unites all situations. In this way, rather than taking normative control over decision-making, artificial intelligence should be incorporated as an operational and epistemological tool that improves its quality.

Ultimately, it may be said that stable ethical and methodological frameworks that are transdisciplinary, verifiable, and cross-disciplinary are necessary for the continued development and use of AI in teaching, assessment, and scientific research. The only way to guarantee that technology progress is in line with the core principles of science and education—fairness, transparency, knowledge verifiability, and social responsibility—is through such an approach. By synthesizing recent ethical, legal, and methodological literature, this paper demonstrates that responsible AI integration in education and scientific research requires governance models that explicitly preserve human accountability, ensure transparency, and support verifiability of knowledge production. At the same time, the scientific literature also highlights certain risks associated with the use of artificial intelligence, including algorithmic bias, the generation of inaccurate or misleading information, challenges related to data privacy and security, and the potential weakening of critical thinking due to excessive reliance on AI systems. Therefore, the responsible and ethically grounded use of AI remains essential in order to mitigate these risks and ensure that technological development supports the fundamental values of science and education

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, M.N.; methodology,M.N. and A.P.; software, V.L. ; formal analy-sis, V.L. and M.D; writing-original draft preparation, M.N.; writing-review and editing, A.P. and M.N. All authors have read and agreed to the published version of the manuscript.

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An Analysis of Social Studies Instructional Applications for the Development of Astronomy Literacy in 7th Grade Students

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Abstract: The European Astronomical Union (EAU) designated the year 2019, as the "Year of Astronomy Literacy," prompting countries worldwide to place greater emphasis on space and astronomy education and to adjust their curricula accordingly. Integrating astronomy literacy into the social studies curriculum is particularly crucial, as the course aims to educate citizens who are able to adapt to evolving national and global conditions and who possess strong problem-solving capabilities. The purpose of this study is to equip the seventh-grade students with cognitive, affective and behavioral competencies related to astronomy literacy within the context of the social studies course. The Astronomy Literacy Scale developed by Özdemir was administered as both a pre-test and a post-test. The research was conducted in Yenişehir district of Bursa, one of Turkey's provinces, during the first semester of the 2023-2024 academic year. The study employed a quasi-experimental design involving 22 students in the experimental group and 22 in the control group. The instructional application was implemented over a five-week period, with two class hours per week. Data were analyzed using the SPSS statistical software package. Following the application, 't was found that there were statistically significant differences between the experimental and control groups across the cognitive, affective and behavioral domains, consistently favoring the experimental group. The findings indicated that the instructional practices integrated into the social studies course contributed meaningfully to the students' astronomy literacy and improved their cognitive, affective and behavioral astronomy-related skills.

Keywords: *Social studies, astronomy, astronomy literacy skills, students, applications.*

Introduction

From antiquity to the present, the existence of the universe, the motion of celestial bodies, and the sun's role as a source of heat and light have sustained human curiosity and driven efforts to investigate and comprehend the cosmic phenomena. The systematic organization of accumulated knowledge eventually gave rise to the science of astronomy. Astronomy literacy refers to the ability to understand and critically evaluate the universe, outer space, celestial bodies, and the movements that occur within these domains (Benli-Özdemir, 2023). In this day and age, individuals are required to possess a basic capacity to understand and question the physical environment they inhabit, along with the dynamic processes unfolding on Earth and throughout the universe. Such competence is attainable through the development of effective astronomy literacy skills. Individuals with advanced astronomy literacy demonstrate strong spatial and abstract thinking, are able to interpret maps and navigate effectively, can infer the consequences of Earth's and other planets' movements, and can meaningfully interpret the developments related to space exploration and research (Taşcan and Ünal, 2015).

The social studies course is an interdisciplinary domain that integrates the social sciences and humanities with the aim of developing essential citizenship competencies (Keskin, Coşkun Keskin, and Taş, 2019). Social studies as a formal subject originated in the United States in 1916 and was implemented in

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schools beginning in 1920. The National Curriculum Standards for Social Studies (NCSS), the leading authority on social studies education in the U.S., emphasized in its 1994 definition that the field encompassed not only the social and human sciences but also drew upon concepts from the natural sciences. At the primary level, the concepts and skills related to astronomy were typically introduced through life sciences courses, whereas at the secondary level they were primarily taught through science and social studies courses.

As far as review of the relevant literature's concerned, there is a substantial body of studies concerning astronomy and astronomy literacy. These studies include those that highlighted the importance of astronomy within the educational contexts (Albrecht and Voelzke, 2010; Erbudak and Yeşilbursa, 2023; Eriksson, 2019; Percy, 2005; Pompea and Russo, 2020; Rosenberg, Bladon, Russo, and Christensen, 2014; Slater, Slater, and Dwyer, 2010); investigations examining students' metaphors and perceptions related to the concept of astronomy (Arıkurt, Durukan, and Şahin, 2015; Bitzenbauer, Navarrete, Hennig, Ubben, and Veith, 2023; Güleç and Çelik, 2022; Grubic, 2022; Çelik, Güleç, and Atasoy, 2025; Karamustafaoğlu and Aktürk, 2016; Uçar and Aktamış, 2019); and studies analyzing teachers' and preservice teachers' attitudes and perspectives toward astronomy (Kuzey, 2020; Yeşil-Asana and Benzer, 2020; Erbudak and Yeşilbursa, 2024; Ezberci Çevik, Bozdemir, Candan Helvacı, and Kurnaz, 2020; Canlas, Picardal, and Picardal, 2024). Furthermore, while some other studies focused on astronomy as a disciplinary subject (Plummer, 2009; Blown and Bryce, 2018; Shen and Confrey, 2007; Yerlikaya and Yerlikaya, 2016; Merakchi, 2018; Eriksson, 2019; Salimpour and Fitzgerald, 2022; Salimpour et al., 2024; Likavcan, 2024), others on studies that established connections between social studies and astronomy (Ekiz and Akbaş, 2006; Berea et al., 2019; Güleç and Çelik, 2022; Erbudak and Yeşilbursa, 2023).

Astronomy literacy over the years has come to be investigated from multiple perspectives within the relevant literature. The studies emphasizing the significance of astronomy literacy were prominent (Alejandro, 2007; Çelik and Güleç, 2025; Love, Murphy and Bonora, 2013; Remie, 2019; Yerlikaya and Yerlikaya, 2016). Additionally, several studies focused on developing the instructional programs aimed at improving the astronomy literacy (Aranbica, Pinochet, and Campusano, 2021; Salimpour, Fitzgerald, and Hollow, 2024; Ünal, 2024), while others assessed students' levels of astronomy literacy and related competencies (Benli Özdemir, 2022; Benli Özdemir, 2023; De Beasi, Orellana, Escapil, and Olaizola, 2015). Given that the studies in astronomy literacy is crucial for cultivating a deeper understanding of the universe in which we live, it is essential to provide the students with the astronomy literacy skills and to explore the effective methods for fostering their development. Therefore, the present study aimed to enhance seventh-grade students' cognitive, affective and behavioral astronomy literacy skills through a five-week instructional program consisting of two-hour sessions each week.

The study first examined the learning areas where astronomy is included in the 2018 social studies curriculum. The examination revealed that information related to astronomy is included in the learning areas of Individual and Society, Culture and Heritage, People, Places and Environment, and Global Connections. In the 2018 Science Curriculum, learning outcomes and skills related to astronomy are addressed more intensively, with a separate learning area called Earth and the Universe (Çelik, 2024). While science education focuses more on cognitive domains, social studies education should include skills related to affective and behavioral domains in relation to astronomy. To this end, learning outcomes related to astronomy can be added to the existing learning areas (Ekiz and Akbaş, 2006; Çelik, 2024).

This study examined the effect of instructional practices designed to develop astronomy literacy on the seventh-grade students' astronomy literacy scores, comparing the experimental and control groups through pre-test and post-test measurements. Specifically, the study sought answers to the following research questions:

1. Is there a statistically significant difference, between the experimental and control groups' pre-test and post-test mean scores on the overall Astronomy Literacy Scale?
2. Is there a statistically significant difference, between the experimental and control groups' pre-test and post-test mean scores on the cognitive dimension of the Astronomy Literacy Scale?
3. Is there a statistically significant difference, between the experimental and control groups' pre-test and post-test mean scores on the affective dimension of the Astronomy Literacy Scale?
4. Is there a statistically significant difference, between the experimental and control groups' pre-test and post-test mean scores on the behavioral dimension of the Astronomy Literacy Scale?

Materials and Methods

This section presents the procedural steps followed throughout the study, detailing the implementation process from the initial preparation phase to data collection and analysis.

Model of the Study

Experimental studies are conducted in an attempt to identify the effect of conditions deliberately created or manipulated by the researcher on a dependent variable (Akcan, 2023, p. 90). Fraenkel, Wallen, and Hyun (2011) described the experimental studies as the systematic observation of outcomes that occurred when specific applications or treatments were introduced. In the field of education, experimental methods are frequently employed in order to compare the instructional approaches and to assess the extent of learners' progress. Büyüköztürk, Çakmak, Akgün, Karadeniz and Demirel (2014) classified the experimental studies into two main categories: single-factor and multi-factor designs. They further stated that multi-factorial designs could be divided into four types; weak experimental designs, true experimental designs, factorial designs, and quasi-experimental designs.

This study used a quasi-experimental design developed by Campbell and Stanley (1996). This is because a quasi-experimental design gives the researcher the opportunity to test the tools they have developed (Akcan, 2023). Specifically, the pretest–posttest matched control group design developed by Campbell and Stanley (1996) was chosen. This particular design allows for a degree of control during the testing of researcher-developed instruments. The inclusion of pretests enables researchers to determine the initial equivalence of groups prior to the application and to interpret the posttest results accordingly (Karasar, 2018, p. 132).

In order to ensure the internal validity, equivalent experimental and control groups were established. The independent variables of the study were the students' group assignment (experimental or control) and their gender, while the dependent variable was their astronomy literacy skill level.

Validity and Reliability in Quantitative Data Analysis

Validity refers to the extent to which a scale measures the construct it is intended to measure without capturing the unrelated characteristics. Reliability, on the other hand, concerns the degree to which a scale consistently and accurately measures the phenomenon for which it was designed (Yıldırım and Şimşek, 2018). The study included the opinions of two experts: a linguistics specialist and a social studies education specialist. In order to ensure the content validity of the Astronomy Literacy Scale and the scale was administered to a total of 16 students so as to establish whether the items were interpreted as intended. According to the results of the Exploratory Factor Analysis, the Kaiser–Meyer–Olkin (KMO) coefficient of the scale was calculated as .702, and it was found that the average reliability coefficient was .75. These values indicated that the scale was both valid and reliable for measuring astronomy literacy.

Data Collection Process

In the present study, initially the necessary permissions were first obtained from Benli Özdemir (2022), the developer of the Astronomy Literacy Scale. Following this, the scale was reviewed by a Turkish language expert and the required adaptations were made. Since it was not ethically appropriate to disclose the actual class sections, the students who participated voluntarily and submitted parental consent forms were selected from the sections designated as 7H and 7G. The scale used in both the pre-test and post-test was comprised of three dimensions; cognitive, affective and behavioral. Initially, the pre-test was administered to both the experimental and control groups. One week after the pre-test, a 10-lesson astronomy literacy instructional plan was implemented by the researcher. The astronomy literacy outcomes were developed by the practitioner, with careful attention to aligning them with the relevant topics in the social studies curriculum. The specific learning achievements addressed in each application are presented in Table 1 below.

Table 1. *Astronomy literacy in social studies achievements regarding the cognitive, affective and behavioral skills*

Application	Achievement	Sub-Achievement	Method	Resource	Evaluation
1-2	Students can analyze the role of media in social change and interaction.	Students can analyze celestial bodies through social media platforms, and they may develop positive attitudes toward the lives and responsibilities of astronauts as a result of these engagements.	Instruction through media-based teaching complemented by the question-and-answer method.	NASA YouTube Spacekamp Turkey videos	Students are asked to imagine themselves as astronauts and write a reflective account of a typical day in the life of an astronaut.
3-4	Students can analyze the role of media in social change and interaction.	Students can follow astronomy-related developments through media applications such as Google Sky, Google Maps, StarWalk, and NASA platforms.	Instruction through media-based teaching complemented by the question-and-answer method.	NASA star walk Skymap google earth Googlemap	Students are asked to use these applications to ask one another questions and to identify objects in space as well as objects on Earth.
5-6	Students can develop an understanding of the processes that compelled the Ottoman Empire to undergo change, particularly in relation to contemporaneous developments in Europe.	Students can develop an interest in learning about astronomical developments that took place in Europe during the Early Modern and Modern periods.	Lecture method, question and answer method,	visual information cards	Students are asked to play the astro game “Söyleçiztabu” and explain the picture cards and again explain the information cards this time by drawing.
7-8	Students can draw inferences about the factors influencing human settlement from past to present by engaging in case study analyses.	Based on the factors influencing human settlement, students can recognize the necessity of astronomy studies for the future and follow current developments in the field of astronomy.	Lecture method Case study method	Question and answer method Case study from the eyes of an astronaut	A case study titled “From the perspective of the astronaut” is distributed to the students, and they are asked to read this case, answer the follow-up questions, and fill in the missing parts of the text.
9-10	Students can evaluate the effects of advancements in production technology on social and economic life.	Students can research the effects of astronomy-related spacecraft on social and economic life.	Narration method Question and answer method Evidence-based teaching method	Information cards related to spacecraft and discourses concerning Turkey’s space studies. Students can solve concept puzzles related to spacecraft.	The class conducts a panel study on spacecraft, during which the contributions of spacecraft technology to the national economy and to individuals’ daily lives are evaluated.

The instructional applications were implemented with the experimental group. One week after the completion of these applications, the post-test was administered to both the experimental and control groups.

Study Group

According to Karasar (2018), the sampling process in a research study is shaped by factors such as the research method, purpose, accessibility, and the degree of control that can be maintained. In the present study, the participants were selected using the convenience sampling, a type of non-random sampling method. Convenience sampling involves choosing a sample that is readily available and easily accessible to the researcher (Fraenkel et al., 2011).

This study was conducted in Turkey. The sample of the study consisted of 22 seventh-grade students enrolled in a school affiliated with the Ministry of National Education in the Yenişehir district of Bursa during the first semester of the 2023–2024 academic year. A total of 44 students participated: 22 in the experimental group and 22 in the control group. In selecting the classes to be included in the study, the information regarding students' academic achievement levels and socioeconomic backgrounds was obtained from the classroom teachers. The classes with similar achievement levels and balanced gender distributions were chosen. Both the experimental and control groups were coded separately by gender. Each group consisted of 22 students, including 11 girls and 11 boys, ensuring equivalence in terms of the gender variable. The students who did not submit parental consent forms were excluded from the study. In order to uphold the ethical standards, all participant information was kept confidential.

After the Astronomy Literacy Scale was administered to the experimental group as a pre-test, a five-week astronomy literacy skill development program was implemented. For this purpose, lesson plans and activities developed by the researcher were utilized. In the social studies lesson plans, 10 lesson plans related to cognitive, affective, and behavioral dimensions utilized teaching methods such as media-based instruction, question-and-answer method, lecture, case study instruction, and evidence-based teaching. Additionally, the researcher designed activities such as flashcards about spacecraft, concept puzzles, a case study from the astronaut's perspective, and an astronomy-related "draw, speak, draw, taboo, astronomy" game. For detailed information on the implemented methods, please refer to Table 1. In alignment with the learning achievements in the social studies curriculum, the sub-achievements related to astronomy were created. As an example of learning outcomes and sub-outcomes, the following sub-outcome has been created for the learning outcome "Discuss the role of media in social change and interaction" in the 7th grade Individual and society learning area: "Analyzes celestial bodies in space through social media. Develops positive attitudes towards the lives and missions of astronauts." For detailed information about social studies learning outcomes and sub-outcomes please refer to Table 1. Instructional activities were designed to enhance students' affective and behavioral dispositions toward astronomy, in addition to supporting their cognitive development. Following the administration of the pre-test to the control group, the lesson taught proceeded according to the standard Ministry of National Education curriculum without the inclusion of the astronomy literacy application.

Quantitative Data Collection Tools

"The *Astronomy Literacy Scale*" developed by Benli Özdemir (2022) was employed in the study. The original scale is comprised of three dimensions; cognitive, affective and behavioral and contains 16 items, of which 11 are positively worded and 5 are negatively worded. The scale retained its original structure and utilized a five-point Likert-type response format. The total scores ranged from a minimum of 16 to a maximum of 80. The scale was translated from English into Turkish and linguistic equivalence was established. A Turkish language expert reviewed the translated items to ensure the linguistic accuracy and cultural appropriateness. Each item was subsequently evaluated individually based on the expert feedback. Following this process, the scale was administered to a pilot group of ten students in the 7th and 8th grades, who were asked to explain the meaning of each item in order to verify comprehension. Through these steps, the linguistic consistency and equivalence of the instrument were confirmed. Exploratory Factor Analysis was conducted to assess the construct validity of the scale. It was found that the Kaiser–Meyer–Olkin (KMO) value was.702, indicating acceptable sampling adequacy and the Bartlett's Test of Sphericity was significant ($p < .05$), demonstrating that the data were suitable for factor analysis

Evidence indicates that the *Astronomy Literacy Scale* is a valid and reliable instrument for assessing students' astronomy literacy skills. The internal consistency coefficients reported by Benli Özdemir (2022) are .70 for the cognitive dimension, .72 for the affective dimension, and .84 for the behavioral dimension. The Cronbach's alpha coefficient for the overall scale is .75, demonstrating that the reliability of the instrument exceeds the commonly accepted threshold of .70. In this respect, the scale can be considered a psychometrically sound tool for measuring astronomy literacy. The cognitive dimension of the scale evaluates students' knowledge of astronomy-related concepts. The affective dimension assesses their attitudes, perceptions, and interest toward astronomy and the behavioral dimension captures information related to their astronomy-related behaviors. In the present study, data were analyzed separately within the cognitive, affective and behavioral sub dimensions.

Collection and Analysis of Quantitative Data

Data were collected from both the experimental and control groups as a pre-test during the study period, after which the application was initiated. One week following the completion of the application, a post-test was administered to both groups. The quantitative data obtained for the study were analyzed using the SPSS 24 statistical software package. Prior to conducting inferential analyses, the distribution of the data was examined to determine whether it met the assumptions of normality. Initially, measures of central tendency, that is, mode, median and mean were reviewed. The close proximity of these values was considered an important indicator of normal distribution. Subsequently, skewness and kurtosis coefficients were analyzed. The fact that these coefficients fell within the acceptable range (+2/−2), combined with a non-significant result in the test of homogeneity of variances ($p > .05$), suggested that the data were normally distributed. As the sample size in each group was fewer than 50 participants, the Shapiro–Wilk test was also employed to assess normality. The non-significant Shapiro–Wilk values further confirmed that the data did not deviate from normality. Accordingly, parametric statistical tests were utilized in the data analysis. A dependent samples t-test was applied to compare the related groups and an independent samples t-test was utilized for comparisons between the unrelated groups. The Shapiro–Wilk test results for the normality analysis are presented in Table 2 below.

Table 2. *Normality Test Result*

	Shapiro-Wilk		
	Statistic	**Df**	**Sig**
Pre-test scale	,975	44	,441
Pre-test cognitive Dimension	,973	44	,385
Pre-test Affective Dimension	,973	44	,381
Pre-test Behavioral Dimension	,976	44	,487
Post-test Scale	,969	44	,275
Post-test cognitive Dimension	,969	44	,284
Post-test Affective Dimension	,934	44	,014
Post-test Behavioral Dimension	,953	44	,069

The results of the quantitative data analyses were systematically tabulated and interpreted in the findings section.

Role of the Researcher

The researcher conducted the study at the school where she was employed. Following the administration of the pre-test to both the experimental and control groups during the same week, without introducing any application, the instructional treatment was initiated in the experimental group and continued for five weeks. Each week, two class hours from the social studies course were allocated to the application activities on the predetermined dates. The implementation phase concluded at the end of the five-week period. One week after the completion of the application, the post-test was administered to the students in both the experimental and control groups.

Ethics Committee Approval

Ethical approval for the present study was obtained from the Bursa Uludağ University Social and Humanities Research and Publication Ethics Committee (Decision No. 2023/07; Date: 25.07.2023).

Materials and methods are the second section of an IMRAD paper. Its purpose is to describe the experiment in such retail that a competent colleague could repeat the experiment and obtain the some or equivalent results. Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

Results

Findings and Discussion on the Pre-Test and Post-Test Mean Scores of the Students in the Experimental and Control Groups on the Astronomy Literacy Scale Scores

Under this heading, the findings related to the four sub-questions are presented and examined under separate sub-sections.

4.1.1. Is there a statistically significant difference, between the experimental and control groups' pre-test and post-test mean scores on the overall Astronomy Literacy Scale? Table 3 illustrates the dependent samples t-test results for the pre-test and post-test scores obtained by the students in the experimental group on the Astronomy Literacy Scale (ALS).

Table 3. *Dependent Samples t-Test Results for the Pre-Test and Post-Test Astronomy Literacy Scores of the Students in the Experimental Group*

	N	Mean	Ss	Sd	T	p
Pre-test	22	3,27	,48	21	-9,34	,000
Post-test	22	4,12	,33			

An examination of Table 3 indicates a statistically significant difference between the pre-test mean score (3.27) and the post-test mean score (4.12) of the students in the experimental group [$t(21) = –9.34$, $p < .05$]. The mean scores showed that this significant difference favored the post-test, suggesting that the application contributed to an improvement in students' astronomy literacy levels.

4.1.2. Is There a Significant Difference Between the Pre-Test and Post-Test Astronomy Literacy Scores of the Students in the Control Group? Table 4 presents the dependent samples t-test results for the pre-test and post-test scores obtained by the students in the control group on the Astronomy Literacy Scale (ALS).

Table 4. *Dependent Samples t-Test Results for the Pre-Test and Post-Test Astronomy Literacy Scores of the Students in the Control Group*

	N	Mean	Ss	Sd	T	p
Pre-test	22	3,36	,49	21	2,699	,01
Post-test	22	3,32	,48			

An examination of Table 4 shows that there was a statistically significant difference between the pre-test mean score (3.36) and the post-test mean score (3.32) of the students in the control group [$t(21) = 2.70$, $p < .05$]. However, the difference between the two mean scores was minimal.

4.1.3. Is There a Significant Difference Between the Pre-Test and Post-Test Astronomy Literacy Scores of the Students in the Experimental and Control Groups? Table 4 presents the independent samples t-test results for the pre-test and post-test scores obtained from the Astronomy Literacy Scale (ALS) by students in the experimental and control groups.

Table 5. *Independent Samples t-Test Results for the Pre-Test and Post-Test Astronomy Literacy Scores of the Students in the Experimental and Control Groups*

	Groups	N	X	Ss	Sd	t	p
Pre-test	Experimental	22	3,27	,49	42	-,653	,518
	Control	22	3,36	,50	42		
Post-test	Experimental	22	4,13	,34	42	6,390	,000
	Control	22	3,32	,49	42		

An examination of Table 5 shows that there was no statistically significant difference between the pre-test astronomy literacy scores of the experimental and control groups, as indicated by the similarity in their mean scores [t(42) = –0.65, p > .05]. However, a comparison of the post-test scores revealed a statistically significant difference between the two groups [t(42) = 6.39, p < .05]. This finding suggested that the instructional application provided to the experimental group had a positive impact on their astronomy literacy levels.

4.1.4. Is There a Significant Difference Between the Pre-Test and Post-Test Astronomy Literacy Scores of the Students in the Experimental and Control Groups by Gender? Table 6 presents the independent samples t-test results conducted to establish whether the pre-test and post-test scores obtained from the Astronomy Literacy Scale (ALS) by the students in the experimental and control groups differed by gender.

Table 6. *Independent Samples t-Test Results for the Pre-Test and Post-Test Scores of the Experimental and Control Groups by Gender*

Group	Gender	Process	X	ss	Sd	t	P
Experimental	Male	Pre-test-Post-test	-1,00	,43	10	-7,644	,000
	Female	Pre-test- Post-test	-0,71	,40	10	-6,03	,000
Control	Male	Pre-test- Post-test	0,73	,09	10	2,797	,019
	Female	Pre-test- Post-test	,020	,08	10	1,00	,341

An examination of Table 6 shows that there was a statistically significant difference between the pre-test and post-test scores of both male students [t(10) = –7.64, p < .05] and female students [t(10) = –6.03, p < .05] in the experimental group. In contrast, it was found that there was no significant difference between the pre-test and post-test scores of male students [t(10) = 2.80, p > .05] or female students [t(10) = 1.00, p > .05] in the control group. Considering the degree of change observed among the male and female students in the experimental group, the results suggested that male students exhibited greater improvement in astronomy literacy following the application.

Findings and Discussion on the Pre-Test and Post-Test Mean Scores of the Experimental and Control Groups for the Cognitive Dimension of the Astronomy Literacy Scale

4.2.1. Is There a Significant Difference Between the Pre-Test and Post-Test Scores on the Cognitive Dimension of Astronomy Literacy for the Students in the Experimental Group? Table 7 presents the dependent samples t-test results for the pre-test and post-test scores obtained by the students in the experimental group on the cognitive dimension of the Astronomy Literacy Scale. The findings are summarized below.

Table 7. *Dependent Samples t-Test Results for the Pre-Test and Post-Test Scores of the Students in the Experimental Group on the Cognitive Dimension of the Astronomy Literacy Scale*

	N	Mean	Ss	sd	T	p
Pre-test	22	3,35	,54	21	-5,265	,000
Post-test	22	3,99	,44			

An examination of Table 7 indicates a statistically significant difference between the pre-test mean score (3.35) and the post-test mean score (3.99) of the students in the experimental group [t(21) = –5.27, p < .05]. The comparison of mean scores showed that this difference favored the post-test, with students achieving higher scores following the application. This particular finding suggested that in addition to the targeted instructional activities aimed at developing the cognitive dimension of astronomy literacy, the cumulative learning that occurred throughout the process contributed positively to the students' cognitive perception. It may also be inferred that students' confidence in their astronomy-related knowledge improved after the application.

4.2.2. Is There a Significant Difference Between the Pre-Test and Post-Test Scores of the Students in the Control Group on the Cognitive Dimension of Astronomy Literacy? Table 8 presents the dependent samples t-test results for the pre-test and post-test scores obtained by the students in the control group on the cognitive dimension of the Astronomy Literacy Scale. The findings are summarized below.

Table 8. *Dependent Samples t-Test Results for the Pre-Test and Post-Test Scores on the Cognitive Dimension of the Astronomy Literacy Scale for the Students in the Control Group*

	N	Mean	Ss	Sd	T	p
Pre-test	22	3,50	,56	21	,358	,724
Post-test	22	3,49	,50			

An examination of Table 8 reveals that there was no statistically significant difference between the pre-test mean score (3.50) and the post-test mean score (3.49) of the students in the control group [t(21) = 0.36, p > .05]. This result indicated that the cognitive dimension scores of the control group did not change from pre-test to post-test, suggesting that students' cognitive astronomy literacy remained stable in the absence of the application.

4.2.3. Is There a Significant Difference Between the Pre-Test and Post-Test Scores on the Cognitive Dimension of Astronomy Literacy for the Students in the Experimental and Control Groups? Table 9 presents the independent samples t-test results for the pre-test and post-test scores obtained by the students in the experimental and control groups on the cognitive dimension of the Astronomy Literacy Scale. The findings are summarized below.

Table 9. *Independent Samples t-Test Results for the Pre-Test and Post-Test Scores on the Cognitive Dimension of the Astronomy Literacy Scale for the Students in the Experimental and Control Groups*

	Groups	N	X	Ss	sd	t	p
Pre-test	Experimental	22	3,35	,54	42	-,935	,355
	Control	22	3,50	,56	42		
Post-test	Experimental	22	3,99	,44	42	3,469	,001
	Control	22	3,49	,51	42		

An examination of Table 9 indicates that there was no statistically significant difference between the pre-test cognitive dimension scores of the experimental and control groups, as reflected in their similar mean scores [t(42) = –0.94, p > .05]. However, comparison of the post-test scores revealed a statistically significant difference between the two groups [t(42) = 3.47, p < .05]. This finding suggested that the instructional application administered to the experimental group had a positive impact on students' cognitive astronomy literacy.

4.2.4. Is There a Significant Difference Between the Pre-Test and Post-Test Scores on the Cognitive Dimension of the Astronomy Literacy Scale for the Students in the Experimental and Control Groups by Gender? Table 7 presents the pre-test and post-test scores of students in the experimental and control groups on the cognitive dimension of the Astronomy Literacy Scale. Independent samples t-test results are provided to establish whether these scores differed by gender.

Table 10. *Independent Samples t-Test Results for the Pre-Test and Post-Test Scores of the Experimental and Control Groups by Gender*

Group	Gender	Process	X	Ss	sd	T	p
Experimental	Male	Pre-test – Post-test	-,64	,61	10	-3,52	,00
	Female	Pre-test – Post-test	-63	,56	10	-3,76	,00
Control	Male	Pre-test – Post-test	,064	,22	10	1,00	,341
	Female	Pre-test – Post-test	-,03	,09	10	-1,399	,192

An examination of Table 10 indicates that there was a statistically significant difference between the pre-test and post-test scores of both male students [t(10) = –3.52, *p* < .05] and female students [t(10) = –3.76, *p* < .05] in the experimental group. This finding indicated that both male and female students benefited from the instructional application in terms of cognitive astronomy literacy. In contrast, it was found that there was no statistically significant difference between the pre-test and post-test scores of male students [t(10) = 1.00, *p* > .05] or female students [t(10) = –1.40, *p* > .05] in the control group. This result indicated that without the application, students' cognitive dimension scores remained stable regardless of gender.

Findings and Discussion on the Pre-Test and Post-Test Mean Scores of the Experimental and Control Groups for the Affective Dimension of the Astronomy Literacy Scale

4.3.1. Is There a Significant Difference Between the Pre-Test and Post-Test Scores on the Affective Dimension of Astronomy Literacy for Students in the Experimental Group? Table 11 presents the dependent samples t-test results for the pre-test and post-test scores obtained by the students in the experimental group on the affective dimension of the Astronomy Literacy Scale. The findings are summarized below.

Table 11. *Dependent Samples t-Test Results for the Pre-Test and Post-Test Scores of the Students in the Experimental Group on the Affective Dimension of the Astronomy Literacy Scale*

	N	Mean	Ss	Sd	t	p
Pre-test	22	3,46	,60	21	-6,312	,000
Post-test	22	4,34	,36			

An examination of Table 11 indicates a statistically significant difference between the pre-test mean score (3.46) and the post-test mean score (4.34) of students in the experimental group [$t(21) = –6.312$, $p < .05$]. The comparison of mean scores demonstrated that this significant difference favored the post-test, reflecting a substantial increase in students' affective scores following the application. These results suggested that the instructional activities implemented in the experimental group had a significant and positive effect on students' affective engagement with astronomy.

4.3.2. Is There a Significant Difference Between the Pre-Test and Post-Test Scores on the Affective Dimension of Astronomy Literacy for the Students in the Control Group? The pre-test and post-test scores of the control group were examined. Table 12 presents the dependent samples t-test results for the pre-test and post-test scores obtained by the students in the control group on the affective dimension of the Astronomy Literacy Scale.

Table 12. *Dependent samples t-test results on the pre-test and post-test scores of the affective dimension of the astronomy literacy scale of the students in the control group*

	N	Mean	Ss	Sd	T	P
Pre-test	22	3,44	,73	21	3,578	,002
Post-test	22	3,37	,76			

An examination of Table 12 indicates that there was no significant difference between the pre-test mean score ($M = 3.50$) and the post-test mean score ($M = 3.44$) of the students in the control group [$t(21) = 0.36$, $p > .05$]. This finding suggested that the pre-test and post-test scores of the control group did not differ for the affective dimension of astronomy literacy.

4.3.3. Is There a Significant Difference Between the Pretest and Posttest Scores on the Affective Dimension of Astronomy Literacy for the Students in the Experimental and Control Groups? Table 13 presents the pretest and posttest scores of students in the experimental and control groups for the affective dimension of the astronomy literacy scale. Independent samples t-test results were also reported.

Table 13. *Independent samples t-test on the pre-test and post-test scores of the affective dimension of the astronomy literacy scale of the students in the experimental and control groups*

	Groups	N	X	Ss	sd	t	p
Pre-test	Experimental	22	3,46	,61	42	-,075	,941
	Control	22	3,45	,73	42		
Post-test	Experimental	22	4,34	,37	42	5,348	,000
	Control	22	3,37	,77	42		

An examination of Table 13 indicates that there was no statistically significant difference between the pre-test scores of the affective dimension of astronomy literacy for the experimental and control groups, based on the students' pre-test mean scores [$t(42) = 0.8$, $p > .05$]. In contrast, a comparison of the post-test scores revealed a statistically significant difference between the experimental and control groups [$t(42) = 5.35$, $p < .05$]. These results suggested that the instructional application provided to the experimental group had a positive effect.

4.3.4. Is There a Significant Difference Between the Pretest and Posttest Scores of Students in the Experimental and Control Groups on the Affective Dimension of the Astronomy Literacy Scale by Gender? Table 14 presents the pretest and posttest scores of students in the experimental and control groups on the affective dimension of astronomy literacy. Independent samples t-test results are provided to establish whether any differences existed based on gender.

Table 14. *Independent samples t-tests on the pre-test and post-test scores of the experimental and control groups by gender*

Group	Gender	Process	X	Ss	sd	t	p
Experimental	Male	Pre-test – Post-test	-1,17	,72	10	-5,35	,00
	Female	Pre-test – Post-test	-,59	,43	10	-4,48	,00
Control	Male	Pre-test – Post-test	,06	,08	10	2,39	,38
	Female	Pre-test – Post-test	,09	,11	10	2,631	,06

An examination of Table 14 indicates a significant difference between the pretest and posttest scores of male students in the experimental group [$t(10) = -5.35$, $p < .05$] and female students [$t(10) = -4.48$, $p < .05$], suggesting a significant effect of the application. In contrast, no significant difference was observed between the pretest and posttest scores of male students [$t(10) = 2.39$, $p > .05$] and female students [$t(10) = 2.63$, $p > .05$] in the control group. These results suggested that the male students achieved greater affective achievements than the female students.

Findings and Discussion on the Pre-Test and Post-Test Mean Scores of the Experimental and Control Groups on the Behavioral Dimension of the Astronomy Literacy Scale.

4.4.1. Is There a Significant Difference Between the Pretest and Posttest Scores of Students in the Experimental Group on the Behavioral Dimension of the Astronomy Literacy Scale? The pretest and posttest scores of the experimental group students on the behavioral dimension of the Astronomy Literacy Scale were compared. Table 15 presents the results of the dependent samples t-test conducted on the pretest and posttest scores of the students in the experimental group.

Table 15. *Dependent samples t-test results for the experimental group on the behavioral dimension of the Astronomy Literacy Scale*

Group	N	Mean	Ss	sd	t	p
Pre-test	22	2,71	,97	21	-7,876	,000
Post-test	22	4,01	,54			

An examination of Table 15 indicates a significant difference between the pre-test mean score (2.71) and the post-test mean score (4.01) of the students in the experimental group [$t(21) = -7.88$, $p < .05$]. Comparison of the group means showed that this significant difference favored the post-test scores (mean = 4.01).

4.4.2. Is There a Significant Difference Between the Pre-Test and Post-Test Scores of Students in the Control Group on the Behavioral Dimension of the Astronomy Literacy Scale? The pre-test and post-test scores of the control group students on the behavioral dimension of the Astronomy Literacy Scale were compared. Table 16 presents the results of the dependent samples t-test conducted on the pre-test and post-test scores of the students in the control group.

Table 16. *Dependent samples t-test results for the control group on the behavioral dimension of the Astronomy Literacy Scale*

Group	N	Mean	Ss	Sd	T	p
Pre-test	22	2,89	,83	21	1,418	,171
Post-test	22	2,81	,78			

An examination of Table 16 indicates no significant difference between the pre-test mean score (2.89) and the post-test mean score (2.81) of the control group students [$t(21) = 1.42$, $p > .05$]. These results suggested that the pre-test and post-test scores of the control group on the behavioral dimension of astronomy literacy did not differ significantly.

4.4.3. Is There a Significant Difference Between the Pretest and Posttest Scores of the Behavioral Dimension of Astronomy Literacy of the Students in the Experimental and Control Group? The pretest and posttests of the Experimental Control group regarding the behavioral dimension of the Astronomy Literacy Scale were compared. Table 17 contains the independent samples t-test results regarding the pre-test and post-test scores obtained by the students in the experimental and control groups from the behavioral dimension of the astronomy literacy scale.

Table 17. *Independent samples t-test on the pre-test and post-test scores of the behavioral dimension of the astronomy literacy scale of students in the experimental and control groups*

	Group	N	X	Ss	Sd	t	p
Pre-test	Experimental	22	2,71	,98	42	-,664	,510
	Control	22	2,89	,83	42		
Post-test	Experimental	22	4,01	,55	42	5,84	,000
	Control	22	2,82	,79	42		

An examination of Table 17 indicates that there was no statistically significant difference between the pre-test scores of the experimental and control groups in the behavioral dimension of astronomy literacy, as reflected in the students' pre-test mean scores [t(42) = -0.66, $p > .05$]. In contrast, the comparison of post-test scores revealed a significant difference between the experimental and control groups [t(42) = 5.84, $p < .05$]. These findings suggested that the instructional approach implemented with the experimental group had a positive effect on students' behavioral astronomy literacy.

4.4.4. Is There a Significant Difference Between the Pre-Test and Post-Test Scores of Students in the Experimental and Control Groups on the Behavioral Dimension of the Astronomy Literacy Scale by Gender? The pre-test and post-test scores of the experimental and control groups for the behavioral dimension of the Astronomy Literacy Scale were compared in terms of the gender variable. Table 18 presents the results of the independent samples t-test conducted to establish whether the pre-test and post-test scores of students in the experimental and control groups differed by gender.

Table 18. *Independent samples t-test on the pre-test and post-test scores of the experimental and control groups, analyzed according to gender*

Group	Gender	Process	x	Ss	sd	t	p
Experimental	Male	Pre-test- Post-test	-1,48	,79	10	-6,20	,00
	Female	Pre-test- Post-test	-1,12	,74	10	-4,49	,00
Control	Male	Pre-test- Post-test	,12	,16	10	2,39	,38
	Female	Pre-test- Post-test	,03	,31	10	,319	,756

An examination of Table 18 indicates that there was a significant difference between the pre-test and post-test scores of both male [t(10) = -6.20, $p < .05$] and female [t(10) = -4.49, $p < .05$] students in the experimental group, suggesting a significant effect of the application. In contrast, no significant difference was observed between the pre-test and post-test scores of the male [t(10) = 2.39, $p > .05$] or the female [t(10) = 3.19, $p > .05$] students in the control group. These findings suggested that the male students in the experimental group exhibited more positive behavioral changes toward astronomy compared to the female students in the same group.

Discussions and Conclusions

The relationship between the scores obtained from the Astronomy Literacy Scale and the pre-test and post-test scores of the experimental and control groups was examined in the present study. In this sense, an initial analysis was conducted to establish whether there was a significant difference between the pre-test and post-test scores of students in the experimental group.

The results of the study indicated that the instructional methods, techniques, and activities employed positively influenced the post-test achievements. The students were able to develop their astronomy literacy skills through engaging and interactive approaches, including concept puzzles, question cards, Tell-Tabuastro and other hands-on activities. These methods facilitated the acquisition of various astronomy literacy skills, such as understanding and observing planetary and constellation movements, drawing inferences, interpreting space-related developments and keeping up with scientific advancements. Consequently, these activities contributed to the development of a range of related behavioral competencies (Taşcan and Ünal, 2015; Merakchi, 2018).

It was revealed that there was no significant difference between the pre-test and post-test scores of astronomy literacy among the students in the control group. This suggested that the existing social studies curriculum topics, such as *Individual and Society* and *Culture and Heritage*, did not contribute to the development of astronomy literacy skills in the control group during the study period. Therefore, it is recommended that astronomy be included in the social studies program, as it can enhance students' conceptual understanding and cognitive development. Astronomy has interdisciplinary connections with social studies, drawing from fields such as sociology, geography, and history (Erbudak and Yeşilbursa, 2023; Güleç and Çelik, 2022; Likavcan, 2024; Salimpour et al.,2024). Moreover, it was also found that there was a significant difference between the pre-test and post-test scores of the experimental and control groups in favor of the experimental group. This indicated that the instructional applications implemented in the experimental group effectively improved the students' astronomy literacy skills.

The study investigated whether there was a significant difference between the pre-test and post-test scores of astronomy literacy in the experimental and control groups, taking gender into account. The results indicated that the male students in the experimental group achieved higher scores in astronomy literacy compared to the female students. This difference may be attributed to a greater interest in space and astronomy among the male students.

Additionally, the study investigated whether there was a significant difference in the pre-test and post-test score averages of the experimental and control groups in the cognitive dimension of the Astronomy Literacy Scale. The results showed a significant improvement in the cognitive scores of students in the experimental group. Even though the study did not include a specific application targeting the cognitive dimension, it was revealed that exposure to various space-related applications and videos contributed positively to the students' cognitive astronomy skills. These results are consistent with those of the previous studies suggesting that astronomy education, including the use of innovative approaches such as augmented reality, can enhance the cognitive dimension of students' astronomy literacy (Arıcı, 2013; Benli-Özdemir, 2023).

No significant difference was found between the pre-test and post-test scores of the students in the control group regarding the cognitive dimension of astronomy literacy. This finding suggested that the learning areas covered by the current social studies curriculum during the one-and-a-half-month study period did not significantly contribute to the cognitive development of students' astronomy literacy. Therefore, integrating astronomy-related content into the social studies curriculum could help enhance students' cognitive astronomy skills (Erbudak and Yeşilbursa, 2023; Güleç and Çelik, 2022; Kuzey, 2020; Yeşil-Asana and Benzer, 2020). In contrast, a significant difference was found between the pre-test and post-test scores of students in the experimental and control groups for the cognitive dimension of astronomy literacy. This indicated that the applications implemented in the experimental group, including the virtual program and various applications, effectively improved the students' cognitive astronomy skills. These results are consistent with previous findings in the field of social studies (Yılmaz and Çolak, 2012; Çolak, 2014; Yılmaz, 2019; Yıldırım and Şimşek, 2023).

Furthermore, the study examined whether the cognitive achievements differed by gender. The results showed that the male students achieved greater cognitive achievements than the female students, suggesting potential gender-related differences in engagement or responsiveness to the applications.

The study investigated whether there was a significant difference between the pre-test and post-test scores of the experimental and control groups in the affective dimension of the Astronomy Literacy Scale. Analysis of the experimental group revealed a significant difference between the pre-test and post-test scores, indicating that the application positively impacted the students' attitudes toward astronomy literacy. These findings suggested that the applied activities fostered the students' interest in astronomy and enhanced their curiosity. Previous research supports this particular result, showing that engaging and varied instructional approaches in astronomy education can increase students' interest and motivation in the subject (Glover, Miller, Averis, and Door, 2007; Çöl and Karaca, 2020; Pompea and Russo, 2020; Rosenberg et al., 2014; Slater, Slater, and Dwyer, 2010).

No significant difference was found between the control group's pre-test and post-test scores for the affective dimension of astronomy literacy. This finding indicated that the content covered in the social studies curriculum during the research period was insufficient to enhance the students' interest and curiosity in the astronomy-related topics. Furthermore, this result supported the conclusion drawn from our review of the social studies textbooks namely, that the textbooks did not adequately foster the astronomy literacy and aligned with the evaluations provided by the participating teachers.

The study revealed a significant difference was between the pre-test and post-test scores of students in the experimental and control groups with respect to the affective dimension of astronomy literacy. This particular finding suggested that interactive applications, such as StarWalk and SkyMap, as well as educational websites (e.g., NASA, TUA, TÜBİTAK) and activities involving concept puzzles and games were effective in fostering the students' positive attitudes toward astronomy (Aktamış and Arıcı, 2013; Yılmaz, 2019).

While a significant difference was identified between the pre-test and post-test scores related to the affective dimension of astronomy literacy across gender in the experimental group, no such difference emerged in the control group. Within the experimental group, it was found that the male students developed a more positive affective attitude toward astronomy literacy compared to their female counterparts.

The study examined whether there was a significant difference between the pre-test and post-test scores of the experimental and control groups on the affective dimension of the astronomy literacy scale. Analysis of the experimental group revealed a significant difference between students' pre-test and post-test scores in this dimension. This finding indicated that the instructional activities implemented during the application positively impacted the students' affective attitudes toward astronomy literacy, increased their interest in astronomy and enhanced their curiosity. Previous studies similarly emphasized that incorporating diverse and engaging applications in astronomy instruction increased students' interest in both the subject and the course (Glover et al., 2007; Ezberci Çevik et al., 2020; Canlas et al., 2024; Çöl and Karaca, 2020).

No significant difference was found between the control group's pre-test and post-test scores on the affective dimension of astronomy literacy. This finding suggested that the astronomy-related content included in the social studies curriculum during the research period was insufficient to enhance the students' interest and curiosity in astronomy. Moreover, this result supported the conclusion drawn from our analysis of the social studies textbooks that the textbooks did not adequately promote astronomy literacy and aligned with the teachers' evaluations indicating similar shortcomings.

The study revealed a significant difference between the pre-test and post-test scores of students in the experimental and control groups regarding the affective dimension of astronomy literacy. This finding indicated that interactive tools such as StarWalk and SkyMap along with educational websites (e.g., NASA, TUA, TÜBİTAK) and activities involving concept puzzles and games, were effective in fostering the students' positive attitudes toward astronomy (Aktamış and Arıcı, 2013; Arıkurt et al., 2015; Bitzenbauer et al., 2023; Taşcan, 2019; Yılmaz, 2014).

While a significant difference was revealed between the pre-test and post-test scores related to the affective dimension of astronomy literacy across gender in the experimental group, no such difference emerged in the control group. Within the experimental group, it was found that the male students developed a more positive affective attitude toward astronomy literacy than the female students.

The study investigated whether there was a significant difference between the pre-test and post-test scores of the experimental and control groups in the behavioral dimension of the astronomy literacy scale. In this context, a significant difference was first identified between the pre-test and post-test scores of the students in the experimental group. This difference indicated that the students exhibited measurable achievements in the behavioral dimension of astronomy literacy. During the application, the students engaged in activities related to the lives of astronauts, utilized sky observation programs such as StarWalk and SkyMap in a structured manner, and were guided in recognizing and effectively using these tools. Consequently, the students developed increased awareness of and positive behavioral tendencies toward space and the sky. These findings suggested that the diverse astronomy-related applications contributed positively to the students' behavioral outcomes (Benli Özdemir, 2022; Aktürk, Yazıcı and Bulut, 2013; Kulaca, 2023; Çelik, Güleç and Atasoy, 2025; Karamustafaoğlu and Aktürk, 2016; Likavcan, 2024; Uçar and Aktamış, 2019).

No significant difference was found between the control group's pre-test and post-test scores in the behavioral dimension of astronomy literacy. Since only the social studies curriculum was implemented and no astronomy-focused applications were introduced, the findings indicated that the content of the social studies program alone did not sufficiently support the development of students' astronomy literacy or related behavioral skills. However, previous studies demonstrated that the students' astronomy competencies could be enhanced through the use of diverse, targeted applications (Aktamış and Arıcı, 2013; Peten and Şirin, 2020).

A significant difference in the behavioral dimension of astronomy literacy was revealed between the pre-test and post-test scores of the experimental and control groups, in favor of the experimental group. This particular result indicated that the instructional activities implemented in the experimental group effectively enabled the students to attain the behavioral competencies required for astronomy literacy. Consistent with this finding, numerous studies reported that the diverse astronomy-related activities enhanced the students' academic performance and strengthened their skills related to space and astronomy (Tian, Endo, Urata, Mouri and Yasuda, 2014; Taşcan, 2019; Kalkan and Yener, 2022).

A significant difference was identified between the pre-test and post-test scores of the experimental and control groups in the behavioral dimension of astronomy literacy when examined in relation to gender. In the experimental group, the male students exhibited more positive behavioral changes toward astronomy compared to the female students. In contrast, no significant gender-related differences were observed among the students in the control group.

This is possible to attribute this result to the absence of any instructional applications in the control group that could have generated a positive effect. Overall, the findings indicated that the activities implemented to enhance the students' astronomy literacy made a meaningful contribution to the development of students' cognitive, affective and behavioral competencies (De Beasi et al., 2015; Love, Murphy and Bonora, 2013; Remie, 2019; Salimpour et al., 2024; Ünal, 2024).

Recommendations

- Astronomy applications such as StarWalk, Skymap, and GoogleEarth, which actively engage students in lessons to develop cognitive, affective, and behavioral skills, can be used.
- Activities such as adaptations of Taboo games, concept puzzles, and flashcards related to astronomy topics can be conducted. • Different and fun teaching methods such as the case study method and evidence-based teaching method can be used in social studies lessons.
- To improve astronomy literacy, schools should be equipped with the essential materials and equipment such as telescopes, sky observation tools, and appropriate technological resources that support practical and inquiry-based learning experiences.
- In-service training programs can be provided for the social studies teachers to enhance their awareness of astronomy and to support the effective integration of astronomy-related content into their instructional practices.
- Students may be taken on annual visits to space-related museums or educational centers to enrich their learning experiences and strengthen their interest in astronomy.
- Astronomy advancements and educational programs implemented by the leading space-faring nations can be scrutinized and adapted for use within the Turkish education system to enhance the quality and scope of astronomy instruction.

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Conflict of interests

The Authors that there is 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 authors.

Institutional Review Board Statement

This study was conducted in strict accordance with the ethical standards of research involving human participants and in line with the principles of the Declaration of Helsinki. The research protocol was reviewed and approved by the Bursa Uludag University Research and Publication Ethics Committee / Social and Human Sciences Research and Publication Ethics Committee (Approval Number: [2023-07], Approval Date: [August 25, 2023]).

Prior to participation, informed consent was obtained from all participants. The participants were informed of the study's objectives, procedures, potential risks and benefits, as well as their right to withdraw at any stage without any negative consequences.

All ethical considerations were observed, including the confidentiality of personal information, voluntary participation, and data protection in accordance with application.

Author Contributions

Conceptualization, data curation, methodology, writing- original draft, M.E.Ç; Software, Visualization, writing- review & editing, validation S.G.; formal analysis, funding, research, project management, resources, and supervision were all performed by M.E.Ç and S.G.

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Artificial Intelligence in Applied Cognitive Psychology: A Commentary

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Abstract: AI integration in applied cognitive psychology demands critical evaluation beyond efficiency metrics. Despite widespread institutional adoption, emerging research reveals concerning patterns including high hallucination rates, deteriorating retention with prolonged exposure, and a consistent tendency to support surface-level task completion at the expense of deeper cognitive processing. These findings align with established principles regarding desirable difficulties, metacognitive monitoring, skill acquisition, and vigilance, suggesting that applications prioritising task completion over cognitive development risk undermining the adaptive expertise essential for complex professional contexts. Methodological weaknesses in existing research, including brief interventions, inadequate control comparisons, and reliance on satisfaction measures, further constrain confident conclusions. Nonetheless, several domains including cognitive accessibility, rehabilitation, vigilance, and adaptive tutoring represent areas of genuine promise where AI's architecture may complement rather than conflict with established cognitive science. This commentary synthesises emerging evidence, examines methodological limitations, proposes research priorities for responsible integration, and reflects on where cautious optimism is warranted.

Keywords: *Artificial Intelligence, Applied Cognitive Psychology, Expertise Development.*

Introduction

The rapid proliferation of generative artificial intelligence systems (Kasneci et al., 2023) presents applied cognitive psychology with methodological opportunities and conceptual challenges across educational, occupational, clinical, and research domains. This commentary examines AI integration through applied cognitive psychology's evidence-based frameworks, focusing specifically on generative AI systems (large language models such as ChatGPT) and AI-enhanced educational tools currently being adopted across institutions. Amidst technological enthusiasm and institutional pressure for AI adoption, applied cognitive psychology can provide sceptical, evidence-based analysis.

Institutional pressures for AI adoption manifest through administrative mandates for technology integration, competitive positioning amongst peer institutions, and commercial partnerships with technology providers, often proceeding without rigorous evaluation of cognitive outcomes (Williamson, 2021). These commercial relationships create conflicts between vendors' financial interests in widespread adoption and cognitive psychology's scientific obligation to assess genuine educational and professional benefits. Technology companies invest substantial resources in marketing AI tools to educational institutions and professional organisations, often emphasising efficiency gains whilst downplaying or ignoring cognitive development outcomes (Jobin et al., 2019). When universities and organisations adopt AI systems through commercial contracts before rigorous empirical evaluation, they prioritise market positioning over evidence-based decision-making, whilst also placing at risk the statutory privacy rights of students, staff, and service users whose data enters commercial systems without adequate scrutiny.

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Applied cognitive psychology must resist becoming complicit in these premature adoptions driven by commercial interests rather than demonstrated cognitive benefits. The field's credibility depends on maintaining independence from technology industry narratives and insisting on rigorous empirical evaluation before endorsing widespread AI integration. As a discipline concerned with understanding and enhancing human cognitive functioning across domains including memory, attention, learning, decision-making, vigilance, and metacognition, we must evaluate AI through established cognitive science frameworks whilst reconsidering foundational assumptions about human-AI interaction.

Current practice reveals troubling disconnection between evidence and implementation: institutions adopt AI based on efficiency gains whilst ignoring cognitive development outcomes; organisations implement decision-support without assessing impacts on professional judgement or situational awareness; technology companies promote tools without addressing skill atrophy or dependency. This commentary synthesises emerging empirical evidence, examining four questions: (1) What do systematic investigations reveal about AI's cognitive impacts? (2) How do findings relate to established principles? (3) What methodological limitations constrain conclusions? (4) What research priorities should guide responsible integration?

Empirical Evidence on AI in Cognitive Psychology Contexts

Recent meta-analytic evidence provides initial empirical grounding for understanding AI's impact on learning outcomes. Synthesis of 51 studies revealed that AI systems demonstrate large positive effects on learning performance ($g = 0.867$) but substantially smaller effects on 'deeper cognitive processing', more specifically, a moderately positive effect on learning perception ($g = 0.456$) and on higher-order thinking ($g = 0.457$; Wang and Fan, 2025). This differential impact pattern aligns with cognitive psychology's longstanding distinction between surface and deep learning (Marton and Säljö, 1976; Yang et al., 2024), suggesting that AI may facilitate utilisation of factual knowledge whilst neglecting deeper understanding, learning, and critical reflection which would encourage long-term professional development (Li et al., 2024; Marshall et al., 2022). AI usage could be a cognitive crutch (Barcaui, 2025), rather than scaffolding deeper learning. Of particular concern is the risk that users operating at a surface level of engagement may uncritically accept AI-generated content, including hallucinated claims, as factual, with this risk amplifying in proportion to the consequentiality of the decision or claim involved. It is worth noting that the meta-analysis itself has attracted methodological scrutiny, with critics noting that the included studies were not assessed for peer-review status, randomisation, or statistical power, a limitation that warrants cautious interpretation of the effect size estimates.

This pattern holds concerning implications beyond educational contexts: if AI similarly facilitates surface-level task completion in professional settings whilst undermining development of deep domain expertise, organisations may cultivate workforces capable of executing routine procedures using AI assistance yet lacking the adaptive expertise required when AI systems fail, prove inapplicable, or when novel situations demand flexible problem-solving. This concern maps onto Argyris and Schön's (1978) distinction between single-loop and double-loop learning: AI may reinforce single-loop responses, in which errors are corrected within existing assumptions, whilst impeding the deeper, paradigm-questioning reflection characteristic of double-loop learning that is essential for adaptive professional expertise.

This pattern gains theoretical significance when considered alongside cognitive load theory (Sweller, 1988; Sweller et al., 1998) and research on desirable difficulties in learning (Bjork, 1994; Bjork and Bjork, 2011, 2020). If AI systems complete cognitive operations that learners or professionals would otherwise perform, generating explanations, constructing connections, monitoring comprehension, then reduced cognitive effort may paradoxically undermine the very processing that supports durable learning and transfer. Yang et al. (2024) distinguish surface from deep learning approaches with generative AI, suggesting that effectiveness depends critically on pedagogical or operational integration rather than mere AI tool availability.

Longitudinal evidence further complicates simple assessments of AI's value for cognitive performance and development. Akgun and Toker (2024) documented that whilst pretesting before AI use enhanced retention, consistent with testing effect research (Roediger and Karpicke, 2006), prolonged AI exposure led to memory decline in their sample of 73 undergraduates. This finding suggests potential time-dependent effects wherein initial benefits may give way to dependency or reduced cognitive engagement, paralleling concerns about calculators and GPS navigation systems affecting mathematical and spatial cognition respectively. Recent research on cognitive offloading to external tools demonstrates that whilst offloading can improve immediate task performance, it frequently results in reduced memory for offloaded information (Grinschgl et al., 2021). Experimental evidence shows that increasing cognitive offloading improves performance but diminishes subsequent memory, with participants showing lower recall for offloaded material compared to internally processed information. Research on cognitive offloading reveals that whilst offloading can temporarily free cognitive resources, it frequently results in skill atrophy when individuals become dependent on tools for operations they previously performed internally (Risko and Gilbert, 2016; Gilbert et al., 2023). Grinschgl et al. (2021) demonstrated that reducing offloading costs led to increased offloading behaviour alongside improved immediate performance but significantly diminished memory in subsequent tests. Ward et al. (2017) found that mere smartphone presence reduces available cognitive capacity even when devices remain unused. These findings suggest AI availability may create similar cognitive costs through reduced encoding effort and increased dependency. In occupational contexts, such patterns are particularly concerning emergency responders, medical professionals, or system operators who rely on AI decision-support may experience degraded performance when AI systems malfunction or when situations demand rapid independent judgement without technological assistance.

Research on AI's impact on critical thinking reveals nuanced patterns requiring careful interpretation. Essel et al.'s (2024) investigation with undergraduates identified improvements in question formulation and information analysis alongside concerning patterns of passive acceptance of AI-generated responses. Similarly, Ododo et al. (2024) documented threats to critical thinking when students uncritically accepted AI information without analytical engagement or scrutiny. These findings resonate with decades of cognitive psychology research emphasising that critical thinking develops through active engagement with challenging material rather than passive consumption of information (Chi, 2009). In professional contexts requiring complex judgement, management decision-making, clinical assessment, safety-critical evaluation, uncritical acceptance of AI recommendations without independent verification represents significant risk.

From a metacognitive perspective, AI systems' inability to model metacognitive monitoring represents a fundamental limitation (Exintaris et al., 2023). Metacognition, encompassing monitoring of one's understanding, recognition of knowledge boundaries, and strategic regulation of cognitive processes, has been established as central to effective learning and expert performance (Flavell, 1979; Schraw and Dennison, 1994). Research on metacognitive calibration demonstrates that professionals who accurately assess their understanding show superior outcomes compared to those with poor confidence-accuracy correspondence (Baars et al., 2014). The illusion of knowing, wherein individuals feel confident despite incomplete understanding, becomes particularly problematic when AI systems provide immediate answers without requiring users to evaluate their own knowledge state first. When AI systems confidently present inaccurate information without appropriate uncertainty calibration, they model precisely the metacognitive dysfunction that cognitive psychology seeks to prevent.

Systematic investigation of AI accuracy reveals substantial concerns for cognitive psychology applications. A recent systematic review documented hallucination rates ranging from 28-91% across AI models, with considerable variance depending on task complexity and domain (Chelli et al., 2024). Specifically, these rates were 39.6% for GPT-3.5, 28.6% for GPT-4, and 91.4% for Bard, indicating substantial variation in reliability across models and making the upper bound largely attributable to an earlier-generation system. Examination of ChatGPT citations found 32.3% were fabricated (MacDonald, 2023), whilst broader systematic reviews indicate that whilst AI can reduce literature review workload by 60-65%, precision varies dramatically from 4.6% to 88% depending on task characteristics (Chelli et al., 2024). These accuracy limitations present challenges for applied cognitive psychology, where interventions, organisational recommendations, and clinical applications must be grounded in accurate representation of research evidence. When AI systems conflate distinct theoretical constructs, misattribute empirical findings, or fabricate research that appears plausible to non-experts, they undermine the evidence-based foundation essential to responsible professional practice, and raise fundamental questions about the conditions under which AI-derived output can be treated as information rather than raw data. Without robust supervisory frameworks and reflexive evaluation practices, practitioners risk ascribing evidential weight to content that is, at best, unverified and, at worst, systematically misleading. In safety-critical domains, incorrect AI recommendations regarding vigilance maintenance, workload management, or decision-support system design could compromise operational safety, particularly in settings such as lifeguarding where failure to detect a hazard can lead to permanent injury or death (Sharpe et al., 2024; Vansteenkiste et al., 2025).

Beyond individual cognitive impacts, AI integration raises substantial equity concerns that applied cognitive psychology must address. Works on digital divides demonstrates that technology access follows existing socioeconomic stratification patterns (Van Dijk, 2020). Critical discussions of AI in education consistently identify digital equity as a major challenge, with AI tools requiring subscription costs, high-bandwidth internet, or advanced digital literacy potentially exacerbating rather than reducing educational and professional inequalities (Rottner et al., 2025). Individuals from under-resourced communities may lack access to AI tools their more privileged peers utilise, potentially widening achievement gaps and limiting social mobility (Mostafa, 2025). Furthermore, AI systems trained predominantly on data from Western, educated, industrialised, rich, and democratic populations may perform poorly for culturally and linguistically diverse users, embedding bias into ostensibly objective technological systems (Rottner et al., 2025). The historical record on which LLMs are predominantly trained reflects not only geographic and economic stratification but also a substantial gender skew, given that recorded history, published scholarship, and digitised public discourse have been disproportionately produced by and about men, creating conditions in which gender bias may be structurally encoded rather than incidental. Applied cognitive psychology's commitment to understanding human cognition across diverse populations demands critical examination of who benefits from AI integration and who faces exclusion or disadvantage. Premature adoption without addressing equity concerns risks institutionalising technological advantages for already-privileged groups whilst disadvantaging those most needing educational and professional support.

Methodological Limitations of Current AI Research

Critical examination of existing AI research reveals substantial methodological weaknesses that constrain confident conclusions about AI's cognitive impacts. Many studies employ brief interventions, typically single sessions or fewer than four weeks, insufficient for assessing impacts on skill development or knowledge consolidation. These brief timeframes may capture initial novelty effects or short-term performance changes whilst missing longer-term patterns including skill atrophy, dependency development, or metacognitive deterioration. In occupational contexts where expertise develops over months or years through extensive deliberate practice, such abbreviated studies cannot adequately assess AI's impact on professional competence.

Control group selection in AI research frequently proves inadequate for establishing AI's unique contribution. Many studies compare AI use against no intervention rather than against evidence-based alternatives, creating situations where any active intervention would likely demonstrate superiority over passive control conditions. Rigorous evaluation requires comparing AI against validated approaches: worked examples, practice testing, or spaced repetition in educational contexts; established decision-support systems or expert consultation in occupational settings. Without such comparisons, apparent AI benefits may simply reflect general support rather than AI-specific advantages.

Outcome assessment represents another critical limitation. Many AI studies rely on self-reported satisfaction, perceived usefulness, or intention to continue use rather than objective cognitive performance measures. Whilst subjective experience matters, it proves insufficient for evaluating cognitive impact. Research consistently demonstrates that learners poorly judge which study strategies produce durable learning (Koriat and Bjork, 2005; Soderstrom and Bjork, 2015), often preferring approaches that create illusions of competence over those supporting genuine mastery. Similarly, AI users may report high satisfaction whilst experiencing metacognitive impairment, dependency development, or skill atrophy undetected by satisfaction measures. Rigorous evaluation demands validated cognitive assessments including retention tests, transfer tasks, and metacognitive calibration measures administered at delayed timepoints.

Sample characteristics further limit generalisability. Most AI research employs undergraduate convenience samples, creating uncertainty about findings' applicability to professional contexts requiring extensive domain expertise. University students and domain experts differ substantially in prior knowledge, metacognitive sophistication, and task approach strategies, factors that may moderate AI's cognitive impact. A medical consultant's interaction with AI decision-support likely differs fundamentally from an undergraduate's use of ChatGPT for essay writing. Extrapolating from student samples to professional contexts risks overlooking critical expertise-related moderators.

Publication bias represents a pervasive concern across AI research. The methodological enthusiasm surrounding AI, combined with commercial interests and institutional pressures, creates conditions favouring positive findings. Studies documenting AI limitations, null effects, or negative outcomes may face publication barriers, potentially biasing the evidence base towards optimistic conclusions. This systematic bias undermines meta-analytic synthesis and evidence-based decision-making.

Theoretical Foundations and Cognitive Science Principles

Established cognitive science principles provide frameworks for understanding AI's impacts and limitations. The concept of desirable difficulties (Bjork, 1994; Bjork and Bjork, 2011, 2020) illustrates that conditions impeding immediate performance often enhance long-term retention and transfer. Strategies including generation, spacing, interleaving, and variation create processing demands that, whilst temporarily reducing performance, strengthen memory and promote flexible knowledge application. If AI systems eliminate these beneficial difficulties, providing immediate answers, removing retrieval demands, minimising error correction, they may inadvertently undermine the cognitive processing essential for durable learning.

The testing effect (Roediger and Karpicke, 2006; Rowland, 2014) demonstrates that retrieval practice produces superior retention compared to repeated study, even when retrieval proves difficult and error-prone. AI systems that provide immediate answers without requiring retrieval bypass this mechanism, potentially reducing long-term retention. Similarly, research on worked examples and problem-solving (Sweller and Cooper, 1985; Kalyuga et al., 2003) reveals complex interactions between learner expertise and instructional support. Whilst worked examples benefit novices, they impede expert learning, a pattern termed the expertise reversal effect. AI assistance may similarly help novices whilst limiting expert development if it eliminates the problem-solving practice essential for building adaptive expertise.

Metacognitive monitoring (Flavell, 1979; Koriat, 2007) enables effective learning through accurate assessment of understanding and strategic regulation of study behaviour. When AI systems provide answers without prompting metacognitive evaluation, users may develop inflated confidence despite incomplete understanding. This metacognitive impairment extends beyond education: professionals using AI decision-support may experience reduced calibration between confidence and accuracy, potentially leading to overreliance on AI recommendations and diminished independent judgement.

Research on skill acquisition (Ericsson et al., 1993) emphasises that expertise requires extensive deliberate practice with immediate feedback on challenging tasks within one's domain. If AI completes tasks that would otherwise constitute deliberate practice, users may never develop the skills essential for independent performance. This concern proves particularly salient in professional contexts where AI may facilitate task completion whilst preventing the practice essential for building adaptive expertise.

Vigilance research (Warm et al., 2008; Hancock, 2013) reveals that sustained attention degrades over time, particularly for rare events in monotonous contexts. AI systems designed to support vigilance may inadvertently reduce operators' attentional engagement, leading to greater performance decrements when AI fails or proves unavailable. In safety-critical domains including lifeguarding, aviation, and medical monitoring, such vigilance decrements could compromise safety (Sharpe et al., 2026).

AI integration raises fundamental epistemological concerns for cognitive psychology's scientific foundations. Traditional scientific understanding emphasises transparent, reproducible reasoning processes that can be evaluated, critiqued, and refined. AI systems, particularly large language models, function as "black boxes" whose decision-making processes remain opaque even to their developers (Rudin, 2019; Ahmed et al., 2022). This opacity fundamentally conflicts with scientific principles of explanatory understanding. When AI provides correct answers through inscrutable processes, it shifts emphasis from explanatory knowledge to predictive performance, a transition that may undermine scientific literacy and critical evaluation skills central to cognitive psychology training. Recent analyses of explainable AI methods reveal that whilst techniques exist to increase transparency, many create false impressions of understanding through inconsistent or misleading explanations (Durán and Jongsma, 2021). Professionals who rely on AI-generated insights without understanding underlying mechanisms may struggle to 1.) recognise when AI fails, 2.) generalise knowledge to novel contexts, or 3.) explain their reasoning to colleagues and clients. It is also worth noting that failure in AI systems is not binary: an unsubstantiated, ethically compromised, or subtly misleading output represents a form of failure even when superficially plausible, and this risk is compounded by the feedback dynamics of large language model training, wherein widely shared or repeatedly accessed hallucinations may be inadvertently reinforced as training data for subsequent model iterations, progressively entrenching inaccurate information within the knowledge base on which the field increasingly relies. This epistemological shift from transparent understanding to opaque prediction represents a fundamental challenge to applied cognitive psychology's commitment to evidence-based practice grounded in comprehensible theoretical frameworks. If practitioners cannot explain how conclusions were reached or assess the validity of AI-generated recommendations, the field risks losing the explanatory coherence that distinguishes professional expertise from algorithmic output.

Research Priorities for Responsible AI Integration

Applied cognitive psychology must establish rigorous research priorities to guide responsible AI integration. Longitudinal studies examining AI's long-term cognitive impacts across diverse populations and contexts are essential. Such research should employ validated cognitive assessments administered at delayed timepoints to capture retention, transfer, and metacognitive effects invisible in immediate performance measures. Studies should examine expertise development trajectories, assessing whether AI use facilitates or impedes progression from novice to expert performance. Comparative studies must evaluate AI against evidence-based alternatives rather than passive control conditions. In educational contexts, comparisons should include worked examples, practice testing, spaced repetition, and other validated learning strategies. In occupational settings, evaluations should compare AI against established decision-support systems, expert consultation, and traditional training approaches. Such comparisons will clarify whether AI provides unique benefits or merely replicates existing effective practices.

Research must examine individual differences moderating AI's cognitive impact. Expertise, metacognitive sophistication, learning strategies, and domain knowledge likely influence how people interact with AI and whether interactions prove beneficial or detrimental. Identifying these moderators will enable targeted recommendations about when, for whom, and under what conditions AI proves appropriate. Ecological validity demands investigation of AI in authentic professional contexts with domain experts performing realistic tasks. University student performance on artificial laboratory tasks may poorly predict professional use of AI for complex judgement, diagnosis, or safety-critical decision-making. Field studies in medical, educational, legal, and engineering contexts will provide essential evidence about real-world impacts.

Research should examine AI's effects on collaborative work and team performance. Most current research focuses on individual users, yet many professional contexts involve teamwork. A conceptually important distinction concerns whether AI functions as an independent contributor to group cognition, a kind of synthetic team member whose outputs influence shared mental models, or as a parallel tool available individually to each member, with substantially different implications for group dynamics, accountability, and collective bias depending on the answer, particularly where a single proprietary system shapes the informational environment of all members simultaneously. AI's impact on communication, coordination, shared mental models, and collective performance remains largely unexplored. Mechanism-focused research should identify the cognitive processes through which AI affects learning, expertise development, and professional performance. Understanding whether AI impacts primarily encoding, retrieval, metacognition, attention, or problem-solving strategies will inform more effective AI design and implementation. Intervention research should examine pedagogical and operational strategies for maximising AI benefits whilst minimising cognitive costs. Such research might explore optimal timing of AI introduction, appropriate scaffolding strategies, methods for maintaining metacognitive engagement, and approaches for preventing unhealthy dependency or skill atrophy.

Beyond empirical research, applied cognitive psychology must engage with governance and regulatory frameworks for AI in professional practice. Currently, minimal professional guidelines exist regarding appropriate AI use in psychological assessment, intervention design, clinical decision-making, or research synthesis (Meskó and Topol, 2023). Analysis of 793 state-level AI bills in the United States identified only 28 explicitly referencing mental health applications, with substantial gaps in professional oversight, harm prevention protocols, and data governance (Shumate et al., 2025). Meta-analysis of 200 global AI governance documents reveals widespread calls for accountability, transparency, and fairness, yet most guidelines remain non-binding recommendations rather than enforceable standards (Jobin et al., 2019). This regulatory vacuum creates risks including inappropriate delegation of professional judgement to AI systems, inadequate informed consent when AI contributes to clinical decisions, and unclear accountability when AI-assisted interventions produce adverse outcomes. Professional psychology organisations must develop evidence-based guidelines specifying when AI proves appropriate, what safeguards protect clients and research participants, and how practitioners maintain competence and professional responsibility, legal obligations under applicable data protection and privacy law, and adherence to the ethical principles enshrined in professional codes of practice when utilising AI tools (Martinez-Martin et al., 2020). Such guidelines should address mandatory training requirements for AI use in professional contexts, standards for evaluating AI system validity and reliability, and protocols for monitoring AI impacts on client outcomes. Applied cognitive psychology must also contribute to broader regulatory discussions, ensuring that AI deployment in educational, clinical, and occupational settings reflects genuine understanding of cognitive impacts rather than uncritical technological enthusiasm. Without proactive engagement in governance development, the field risks having AI regulation imposed by policymakers lacking psychological expertise, potentially mandating practices inconsistent with cognitive science evidence.

The Authors Optimism

It is worth acknowledging upfront that the applications highlighted in this subsection are inevitably shaped by the authors' own research interests and should be read accordingly. With that caveat noted, genuine promise does exist alongside the documented limitations and identifying where AI's cognitive footprint may differ substantially from the educational and professional contexts critiqued above is not a rhetorical gesture towards balance but a precondition for directing the research agenda towards the most consequential questions. One underappreciated area of genuine promise concerns AI's potential to support its own quality assurance. There is a credible case that AI systems, embedded within appropriately designed supervisory frameworks, could be leveraged to detect the probabilistic signatures of hallucinated content, flag claims that fall outside the evidential range of reliable training data, and generate calibrated uncertainty statements that prompt rather than suppress critical evaluation. Such an application would not resolve the foundational epistemological concerns raised elsewhere in this commentary, but it would represent a meaningful step towards reflexive AI deployment, one in which the technology participates in the governance of its own outputs rather than leaving that burden entirely to users who may lack the domain knowledge to identify what they are being given.

Cognitive accessibility and neurodivergent populations represent one of the most compelling and underexamined areas of opportunity. For individuals with dyslexia, ADHD, autism spectrum conditions, or acquired cognitive impairments, AI-driven tools including adaptive text reformatting, real-time summarisation, and executive-function scaffolding offer the potential to reduce extrinsic cognitive load in ways that may genuinely support rather than bypass cognitive engagement. The desirable difficulties framework may apply quite differently when the difficulty being reduced is a structural barrier rather than a productive cognitive challenge, and applied cognitive psychology has the theoretical vocabulary to articulate this distinction precisely, yet this literature has developed largely in isolation from mainstream AI cognition research. Further, AI-personalised cognitive training and rehabilitation programmes offer a second area of considerable promise. Unlike general-purpose LLMs, systems designed for dementia prevention, acquired brain injury rehabilitation, or age-related cognitive decline are structured explicitly to exercise cognitive mechanisms rather than offload them, making the dependency and skill atrophy concerns raised throughout this commentary considerably less salient. The capacity of AI to personalise difficulty trajectories, monitor engagement, and deliver intervention at scale addresses a genuine limitation of traditional programme delivery.

A third underexplored application lies in vigilance augmentation within safety-critical domains. The distinction between AI as attentional substitute and AI as perceptual amplifier maps directly onto existing cognitive theory around levels of automation and situation awareness, representing a domain where vigilance research could yield practically significant design principles across lifeguarding, air traffic control, and intensive care monitoring. Finally, adaptive intelligent tutoring systems that embed retrieval practice, spacing, and metacognitive prompting represent an application where AI architecture can be aligned with established learning science rather than placed in tension with it. These systems predate the current wave of generative AI and carry a more robust empirical foundation. The prospect of realising such applications responsibly is itself a compelling reason for the field to invest in exactly the methodological standards and governance frameworks this commentary advocates.

Conclusion

AI integration in applied cognitive psychology requires evidence-based evaluation of cognitive impacts rather than uncritical adoption driven by technological enthusiasm or institutional pressures. Current evidence reveals differential effects, with AI supporting surface learning more effectively than deeper cognitive processing. Substantial methodological limitations constrain confident conclusions about AI's long-term impacts on expertise development, metacognition, and professional performance. Established cognitive science principles regarding desirable difficulties, testing effects, metacognitive monitoring, skill acquisition, and vigilance provide frameworks for understanding both AI's potential benefits and risks. Critical analysis reveals concerning equity implications, epistemological challenges, and governance gaps that demand urgent attention.

Responsible integration demands systematic investigation addressing current methodological weaknesses through longitudinal designs, appropriate control comparisons, objective cognitive assessments, diverse samples, and authentic professional contexts. Applied cognitive psychology must resist institutional pressures for premature adoption, instead providing sceptical, evidence-based analysis of when, for whom, under what conditions, and through what mechanisms AI enhances or undermines cognitive functioning. Only through rigorous empirical investigation and proactive governance engagement can the field fulfil its responsibility to promote genuine cognitive development rather than mere task completion in an increasingly AI-integrated world.

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Digital Communication Platforms for Institutional Branding: A Conceptual Review of Learning, Digital Literacy, and AI/MI Integration

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Abstract: This paper examines the role of digital communication platforms in institutional branding in higher education, with particular attention to learning processes, digital literacy, and the integration of artificial intelligence (AI) and machine learning (ML). Based on a structured review and theoretical synthesis of interdisciplinary literature, the study conceptualizes institutional branding as a dynamic and relational process shaped by digitally mediated interactions among multiple stakeholders.The analysis integrates three interrelated dimensions: digital communication platforms and institutional strategies, stakeholders' digital literacy as a mediating factor in engagement and trust formation, and the role of AI/ML systems in personalizing content, shaping visibility, and quantifying engagement, including their ethical implications. The paper argues that digital platforms function as infrastructural spaces for the co-creation of institutional reputation, while digital literacy enables meaningful engagement and trust. At the same time, AI/ML systems enhance communicative efficiency but introduce reputational and ethical risks. The study proposes a conceptual framework to support future empirical research and the development of responsible communication strategies in higher education.

Keywords: *digital communication platform, institutional branding, learning, digital literacy, artificial intelligence; machine learning.*

Introduction

The way higher education institutions interact with students, partners, and the general public is undergoing a significant transition in the current digital ecosystem. Social media, web portals, and virtual communities are examples of digital communication platforms that are now essential instruments for developing institutional identity and brand as well as for disseminating information. The brand of a university is now a dynamic process of communication, engagement, and shared learning rather than a static symbol (Hemsley-Brown et al., 2016). Digital literacy, organizational learning, and cutting-edge technologies like artificial intelligence (AI) and machine learning (ML), which collectively create new patterns of communication, engagement, and trust, must all be integrated for such a transition.

In order to effectively participate in educational and communication activities, digital literacy is now regarded as a crucial requirement. Digital literacy in higher education, according to Spante, Hashemi, Lundin, and Algers (2018), is a collection of technical, cognitive, and social skills that allow for the responsible and critical use of digital technology. Further studies (Ilomäki et al., 2016; López-Núñez et al., 2024) show that digital literacy affects not just technology proficiency but also views of trustworthiness, credibility, and involvement in online groups. This implies that the degree of digital literacy has a direct impact on how the public, staff, and students view and assess an institution in the context of institutional branding (Vuković et al., 2023).

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In addition to digital competencies, communication platforms represent the core of the interactive relationship between an institution and its stakeholders. According to Pawar (2024), social media have become the dominant space for branding in higher education because they enable two-way communication and the creation of personalized messages. Craig (2022) emphasizes that a university's online presence, combined with transparent communication and authentic content, builds reputation and enhances institutional prestige. Digital communication, therefore, functions not merely as a marketing instrument, but as a mechanism for creating trust and shared values.

Over the past ten years, technological advancements have significantly altered the development and analysis of brand messages. Zawacki-Richter, Marín, Bond, and Gouverneur (2019) indicate that the deployment of AI in higher education is most typically oriented toward tailoring the learning experience and assessing participation. De Mauro, Greco, and Grimaldi (2022) note that machine learning increases communication relevance in the marketing domain by enabling audience segmentation, behavior prediction, and message automation. According to some writers (Huang and Rust, 2018), artificial intelligence (AI) is becoming a crucial part of services and communication processes because it enables information to be tailored to users in real time, boosting perceived value and brand loyalty.

The role of artificial intelligence in institutional branding, however, is not only technical but also epistemological and ethical (Lunić and Ćesarević, 2025). The links between reputation, identity, and trust have changed as a result of the use of digital technology in education. This poses a crucial question: can AI and ML-powered digital communication platforms actually enhance brand authenticity and transparency, or do they run the risk of turning it into an algorithmic construct? From chatbots to deepfakes, artificial intelligence is gradually altering ordinary life—but not without prompting major public concern. A 2025 study by Statista Consumer Insights in the United States found that the primary concerns associated with artificial intelligence are job displacement, manipulation, and disinformation (Figure 1). More than 40% of respondents mentioned each of these problems, with misinformation (45%) and manipulation (46%) ranking highest (Gaudiaut, 2025). Therefore, an integrated consideration of the roles of digital literacy, AI/ML, and institutional communication becomes essential to ensure a balance between efficiency and ethical responsibility.

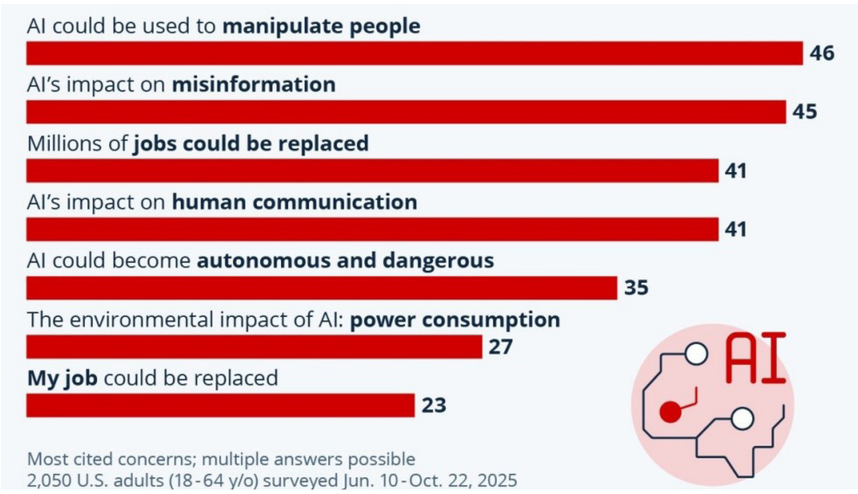

Figure 1. *Scams, Fake-News, Jobs: The Biggest AI Concerns*

Source: Gaudiaut,T. (2025)

Even though the amount of research on branding in higher education is increasing, the literature is still dispersed, with studies frequently concentrating on discrete elements—like digital marketing strategies, stakeholder engagement, or brand identity—without incorporating them into a cohesive and thorough theoretical framework (Palomino, Meza, and O'Brien, 2026). Furthermore, the majority of review studies that are currently available focus on particular branding subdomains or communication tactics, but they hardly ever look at the relationships between digital communication platforms, stakeholders' digital literacy, and algorithmic mediation through AI and machine learning systems at the same time.Consequently, there is a lack of a clear integrative framework that connects digital engagement, digital literacy, and algorithmic influences on institutional reputation and brand co-creation. This gap limits the ability to synthesize existing knowledge and to identify well-grounded directions for future empirical research and theoretical development.

Digital Communication Platforms and Institutional Branding in Higher Education: Co-Creating Reputation through Engagement and Digital Literacy

Contemporary literature on branding in higher education increasingly moves away from linear and marketing-reductionist brand models, introducing a relational and multi-stakeholder perspective. Universities function as complex organizations in which reputation is not built exclusively through institutional messages, but through the continuous interaction of diverse actors—students, faculty, alumni communities, employers, research partners, and the broader public (Balmer and Liao, 2007).

Chapleo (2010) emphasizes that the university brand is inherently fragmented, as different stakeholder groups apply different evaluation criteria (academic quality, employability, social prestige, internationalization). Consequently, reputation cannot be centrally "managed," but is co-created through stakeholders' experiences, narratives, and evaluations.

This approach is further developed in studies that conceptualize the university as a service organization, where the brand emerges through the experience of using educational and communication services (Ng and Forbes, 2009). In this context, reputation is created through regular digital interactions that become publicly accessible and permanently stored on platforms, in addition to formal rankings or institutional pronouncements. Because they allow for the simultaneous visibility of institutional messages, their public interpretation and evaluation, and the active participation of users in the co-creation of brand meaning, digital communication platforms in higher education can be considered the infrastructure of institutional reputation. Reputation is shaped not only by planned institutional communication but also by a dynamic exchange of meanings and social validation that takes place on communication platforms in such a digitally mediated environment, making them a crucial mechanism of modern institutional branding (Constantinides and Zinck Stagno, 2011).

According to research, social media serve as venues for discussion and symbolic exchange in addition to being commercial channels. Reputation is built through observable engagement patterns on these platforms (Ivy, 2008; Constantinides and Zinck Stagno, 2011). According to empirical research, views of institutional openness and credibility are positively impacted by two-way communication, prompt responses, and transparent content management (Constantinides and Zinck Stagno, 2011). On the other hand, one-way communication that is solely promotional frequently leads to low participation and minimal reputational benefits. User-generated content (UGC) plays a particularly crucial function, as it represents authentic reputational signals that viewers typically regard as more trustworthy than institutional communications. Positive student experiences, alumni stories, and interactions in comment sections contribute to reputation building through social validation (Hemsley-Brown and Goonawardana, 2007).

For digital communication platforms to truly enable the co-creation of institutional reputation, users must possess an adequate level of digital literacy and competence. Contemporary research suggests that digital literacy goes beyond mere technical skill and includes the ability to critically evaluate information, understand context and content sources, and participate ethically and responsibly in digital communities—factors that directly affect engagement quality and the formation of trust in institutional communication (Ng, 2012).

Digital competency affects how students in higher education evaluate the reliability of sources, discern between promotional and informational content, and interpret institutional messaging. According to several writers (Lea and Jones, 2011), students who are more digitally literate participate in online communication more actively and thoughtfully, which has a direct impact on the quality of interaction. Additionally, people who comprehend how digital platforms work are more likely to perceive clear communication as an indication of institutional dependability, making digital literacy a mediating factor of trust (Kimmons and Veletsianos, 2018). In this way, digital literacy influences both the level of participation and its impact on one's reputation.

Linking reputational results with the idea of brand equity in higher education is necessary for further development of institutional brand co-creation in digital contexts. According to empirical research, views of academic quality are not the only factors that contribute to university brand equity; interactions with the institution also shape emotional and relational aspects. According to Pinar et al. (2014), aspects of university brand equity that are increasingly impacted by digital communication channels include perceived quality, brand connotations, and student loyalty. Accordingly, digital platforms contribute not only to brand visibility, but also directly to the buildup of institutional reputational capital.

It is particularly important to note that the effects of digital communication on reputation are not evenly distributed among all users. Differences in digital skill levels and patterns of digital media use can significantly influence how institutional messages are perceived and trusted. Research on digital inequality shows that the contemporary "digital divide" relates less to access to technology and more to differences in the ability to use digital tools effectively and critically (van Deursen and van Dijk, 2014). In higher education, these differences have direct branding implications: students with more developed digital competencies are more inclined toward active engagement, deeper content interpretation, and more differentiated assessments of institutional credibility.

Reputation and brand equity must be explicitly introduced as dependent outcomes, with engagement, trust, and perceived usefulness acting as mediating mechanisms, in order to more clearly link the AI/ML component with branding outcomes. AI-driven personalization, for instance, may improve message relevance and user experience quality, but its impact on engagement is not guaranteed; rather, it depends on whether audiences view personalization as beneficial and trustworthy. According to empirical research, the primary mediators between AI personalization and user engagement on social media are perceived utility and trust (Teepapal, 2025). This suggests that AI/ML systems have an indirect impact on reputation in the context of institutional branding by altering perceptions of institutional legitimacy, relationship quality, and interaction intensity.

Beyond personalization, generative AI introduces a new class of mechanisms that can influence branding outcomes through measurable communication performance. Research shows that AI-generated and AI-optimized content can outperform human-generated content in producing digital engagement (likes, comments, shares), which is significant because engagement metrics often function as immediate signals of brand visibility and public evaluation in platform environments (Huang and Zhou, 2025). It is therefore useful to introduce a conceptual linkage: AI content optimization → increased engagement and visibility → strengthening of reputational signals → accumulation of institutional brand equity and trust.

When these insights are combined, it becomes clear that the relationship between digital communication platforms, engagement, and institutional reputation is not linear but rather depends on users' operationalization of digital resources and their competencies (Stanković et al., 2024; Franjić, 2025). Thus, digital literacy can be viewed as both an individual skill and a systemic element that affects how well reputational tactics work in higher education. Neglecting this aspect puts universities at risk of gaining attention without involvement or trust without having a lasting effect on their reputation. Conversely, effectively connecting communication platforms with the development of digital capabilities among students and other stakeholders constitutes a vital prerequisite for a successful institutional brand in the digital era.

Artificial Intelligence and Machine Learning in Institutional Branding: Communication Optimization, Engagement Analytics, and the Management of Ethical Risks

The application of artificial intelligence (AI) and machine learning (ML) in institutional communication does not merely represent a technological upgrade of existing digital platforms, but rather a structural transformation in the way communication signals are produced, distributed, and evaluated. In contemporary digital ecosystems, AI systems function as invisible intermediaries between institutions and audiences, shaping content visibility, information hierarchies, and patterns of engagement (Kaplan and Haenlein, 2019; Hamadi, 2025).

In the context of branding, AI enables institutions to move from generic communication toward dynamic personalization, in which the content, timing, and format of messages are adapted to users' behaviors and interests. Huang and Rust (2021) emphasize that AI in service and communication processes transforms how organizations create value, as it enables scalable yet individualized interaction with large numbers of users.

In reality, advanced algorithmic techniques that allow for the tailoring of digital communications, the study of evaluative tone in communication, and the predictive assessment of user involvement are the most common ways that AI and ML are used in institutional branding. These methods include content recommendation systems, automated sentiment analysis, and models for projecting future interaction patterns. According to research, audience engagement and brand perception are directly impacted by AI-supported personalization and recommendations. This is because algorithmically optimized communication strategies not only increase message relevance but also influence how users interact with institutional entities in digital environments. Stronger engagement and brand-related interactions follow (Hardcastle, Vorster, and Brown, 2025).

Marketing literature demonstrates that ML models enable more precise audience segmentation and behavior prediction compared to traditional analytical approaches (Davenport, Guha, Grewal, and Bressgott, 2020). In higher education, these tools are increasingly used to optimize communication with prospective students, manage reputational crises, and measure the effects of digital campaigns. However, as Wedel and Kannan (2016) note, algorithmic optimization of communication alters the very nature of marketing and reputational decision-making: instead of strategic planning at the institutional level, a portion of control shifts to data-driven models that learn autonomously, often without full transparency.

In an algorithmically mediated communication environment, engagement is no longer solely the result of content quality and strategy, but also an outcome of algorithmic selection. Post visibility, feed prioritization, and recommendation mechanisms directly affect which reputational signals become dominant. As a result, reputation is increasingly shaped through quantified attention metrics (engagement metrics), which AI systems use as input data for further optimization (Grewal, Hulland, Kopalle, and Karahanna, 2020).

There are two effects from this process. On the one hand, it enables organizations to more accurately track audience responses and modify communication as necessary. However, there is a chance that reputation will be diminished to what is algorithmically "visible" rather than what is useful from an educational or social standpoint. In an educational setting, when qualitative aspects like academic integrity, critical thinking, and social responsibility are not always readily quantifiable, this tendency is especially troublesome. Transparency, bias, and manipulation concerns are unavoidably brought up by the use of AI/ML in institutional branding. According to Floridi et al. (2018), algorithms that maximize communication may prefer particular kinds of material, audiences, or narratives, which could lead to a selective and possibly distorted structuring of institutional reputation.

Bucher (2018) warns that users are often ignorant of how algorithms impact what they see, leading to power asymmetries between institutions, platforms, and audiences. Such disparities could erode confidence in an educational setting if AI technologies are exploited to artificially magnify positive signals or to hide negative feedback. Additionally, biases in data may result in the systematic favoring of particular user groups, which has obvious ethical and reputational ramifications (Martin, 2019). The necessity of responsible AI governance, including explainability, auditability, and transparent institutional accountability, is thus emphasized in current literature.

Data leaking via generative AI has emerged as the top AI-related cybersecurity threat, according to the World Economic Forum's Global Cybersecurity Outlook 2026 study, which was released on January 12, 2026 (Figure 2). Surpassing the improvement of hacking skills (29%), 34% of the more than 800 cybersecurity leaders surveyed between August and October 2025 named this issue as the primary danger for 2026. In contrast to prior years, when attacker innovation was seen as a much bigger AI-related threat than data leakage (for 2024 and 2025, over 40% of respondents identified offensive capabilities, while about 20% suggested data exposure), this signals a substantial shift.

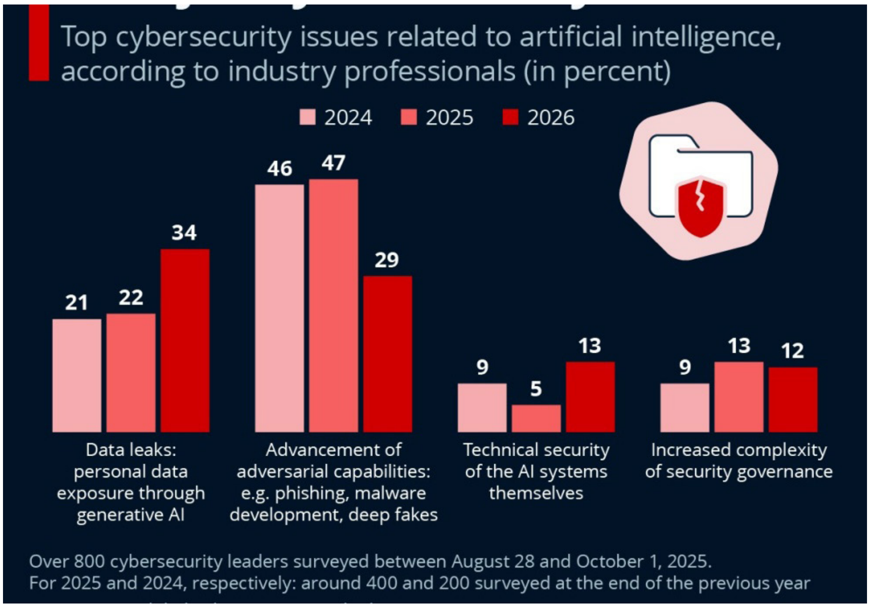

Figure 2. *Data Leaks Through AI Become a Major Cybersecurity Concern*

Source: Gaudiaut, T. ,2026

Further understanding of the role of artificial intelligence in institutional branding requires that algorithmic systems be viewed not only as tools for communication optimization, but as socio-technical systems that actively participate in shaping organizational legitimacy and reputation. Algorithmic decisions regarding content visibility, information ranking, and interaction priorities have normative consequences, as they influence which voices, narratives, and reputational signals become dominant in the digital space. Mittelstadt et al. (2016) emphasize that algorithmic systems generate ethical and social effects even when they are not explicitly designed for normative decision-making, because they inevitably reflect the values embedded in data, objective functions, and design assumptions.

In the context of higher education, these implications are particularly sensitive, given that institutional reputation has long-term consequences for academic legitimacy, social trust, and access to resources. Algorithmic amplification of certain types of content (e.g., marketing-attractive but pedagogically shallow messages) may lead to reputational asymmetries, in which quantified engagement indicators are misinterpreted as signals of institutional quality. This further reinforces the need to examine AI systems in institutional communication through the lens of responsible and human-centered design, rather than exclusively through performance metrics.

Contemporary approaches to human-centered AI emphasize that artificial intelligence systems must remain under clear human oversight and be designed to support, rather than replace, organizational judgment and responsibility. Shneiderman (2020) argues that trust in AI systems depends on their intelligibility, predictability, and the possibility of human intervention—factors that are crucial in reputation-sensitive domains such as education. In institutional branding, this implies that algorithmic tools for engagement analytics and communication personalization must be transparent with regard to optimization criteria and limitations, in order to prevent reputation from becoming an unintended by-product of opaque technical processes.

By integrating these insights, it can be concluded that AI/ML systems in institutional branding play a dual role: they simultaneously represent a powerful instrument for enhancing communication and a potential source of reputational and ethical risks. Sustainable application of artificial intelligence in this domain requires the establishment of clear governance principles that include algorithmic explainability, bias assessment, data protection, and the preservation of human accountability. Only within such a framework is it possible to align technological efficiency with the core values of higher education and to preserve trust in the institutional brand within an algorithmically mediated public sphere.

Conclusion

The analysis of relevant literature on digital communication platforms in the context of institutional branding in higher education indicates that the contemporary university brand cannot be understood as a static marketing construct, but rather as a dynamic, relational, and technologically mediated process. According to current research, ongoing digital interactions between various stakeholders shape educational institutions' identities, images, and reputations. Communication, engagement, and visibility are emerging as crucial components of brand co-creation in the public domain. Digital communication platforms serve as an infrastructural framework where institutional narratives, user experiences, and reputational signals interact and are constantly reinterpreted, according to the theoretical synthesis of the literature. In this way, platforms serve as venues for the negotiation, assessment, and public validation of institutional meaning through social interaction and engagement patterns rather than just being vehicles for the dissemination of messages. This perspective underscores the need to conceptualize institutional branding in higher education through a multi-stakeholder and relational lens, rather than through linear models of image management.

Furthermore, the literature highlights digital literacy and user competencies as important mediating factors between communication strategies and reputational outcomes. Stakeholders' ability to critically interpret digital content, understand the context and sources of information, and participate responsibly in online communities influences both the quality of engagement and the formation of trust in the institution. From this perspective, institutional branding in digital environments depends not only on technological solutions or communication tactics, but also on the development of the competencies of actors involved in the co-creation of reputation.

The data also reveals that the integration of artificial intelligence and machine learning provides an additional level of complexity into institutional branding. Through content personalization, engagement analytics, and predictive modeling, AI/ML systems can improve communication efficiency while also influencing the formation, measurement, and interpretation of reputation in algorithmically mediated environments. According to the literature, these systems affect visibility, attention, and reputational signals rather than functioning impartially. This calls for careful governance and critical analysis of their function in the educational setting.

Because of this, the literature acknowledges the ethical aspect as an integral part of institutional branding built on digital platforms and AI/ML technology. The preservation of institutional accountability, bias control, algorithmic transparency, and data protection appear as critical prerequisites for upholding long-term reputation and confidence in higher education. The literature cautions that in the absence of such frameworks, reputation could be reduced to measurements of short-term attention rather than being based on ideals that are essential to higher education. The institutional brand in higher education is created at the nexus of digital communication platforms, communication tactics, stakeholders' digital literacy, and algorithmically mediated interaction processes, according to a synthesis of the theoretical ideas presented. The contribution of this paper lies in integrating these perspectives into a unified conceptual framework, which may serve as a foundation for future empirical research as well as for the development of more responsible and sustainable institutional communication strategies in the digital and AI-mediated era.

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, D.D; methodology,D.D; software, B.V; formal analy-sis, G.K. and M.I.K.; writing-original draft preparation, D.D.; writing-review and editing, D.D. , and B.V.. All authors have read and agreed to the published version of the manuscript.

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Education in the Age of AI: Adaptive Systems, Assessment, and Responsible Governance

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Abstract: This paper examines how Artificial Intelligence in Education (AIED) is reshaping teaching and learning, drawing on a systematic literature review alongside policy analysis to explore practical applications, the theories behind them, and their governance consequences. Adopting the EU AI Act's risk-based lens, we investigate the ways in which regulatory demands—ranging from transparency and data stewardship to human oversight and provider accountability—influence how AIED tools are built and taken up in practice. We group current uses into four areas—adaptive learning, intelligent assessment, learner profiling, and emerging tools—and read them through the prism of well-known learning theories such as constructivism. The analysis underscores that while these technologies hold real promise, several prominent use cases—automated grading and learner profiling, for instance—fall squarely within the EU AI Act's higher-obligation categories, which means equity, explainability, and genuine human control are not optional but essential for public trust. On the basis of these findings, we put forward concrete, compliance-oriented recommendations aimed at helping educators, institutions, and policymakers deploy AI responsibly across varied educational settings.

Keywords: *Artificial Intelligence, Education, Adaptive Learning, EU Artificial Intelligence Act, Transparency, Policy and Governance.*

Introduction

In the last ten years or so, advances in artificial intelligence (AI) have profoundly changed the way educators and researchers think about what educational technology can achieve. Whether through personalized tutoring platforms or systems that grade student work automatically, AI now sits at the heart of education's digital shift. Yet this growing ubiquity also brings thorny questions about ethical boundaries, built-in biases, learner privacy, and fairness (U.S. Department of Education, 2023). The U.S. Department of Education (2023) characterizes AI as a form of pattern-driven automation: machines go beyond mere data collection to recognize regularities and act on them within educational settings.

When AI takes on tasks that were once the sole province of educators—deciding what a student should study next, or flagging someone as at risk—it introduces responsibilities that schools have not previously had to manage. What makes AI significant in education is not just what it can do technically, but how it is beginning to reshape the very acts of learning, teaching, and assessment. "AI in education can only grow at the speed of trust," the report highlights (U.S. Department of Education, 2023).

For that reason, any deployment needs to be anchored in transparency and shared accountability,

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with teachers, students, families, and policymakers all having a seat at the table. We ground our discussion in the European Union's AI Act and its risk-based logic, which treats applications like automated assessment and learner profiling as areas where stronger safeguards—greater transparency, tighter data governance, and real human oversight—are non-negotiable.

Our review of the literature identifies four broad clusters of AI use in education: adaptive learning and personalized tutoring; intelligent assessment and management; learner profiling and outcome prediction; and novel AI-driven products (Wang et al., 2024).

The bulk of existing research concentrates on higher education, leaning on theoretical lenses like constructivism, learning-styles frameworks, and cognitive models (Wang et al., 2024). Scholarly attention to AI in education surged after 2017, a trend closely tied to the rise of generative AI tools and the rapid pivot to remote learning prompted by COVID-19. By 2022, researchers had scrutinized over 2,200 publications in an effort to chart the intellectual terrain of this field—work that reveals an increasingly multidisciplinary landscape bridging computer science, education studies, and information-systems research (Wang et al., 2024). At the same time, the U.S. Department of Education (2023) flags several pressing dangers: biased training data, erosion of student privacy, automation that outpaces human oversight, and AI models built without adequate theoretical foundations (U.S. Department of Education, 2023).

If left unchecked, AI risks deepening the inequalities already present in education, which is precisely why current guidelines stress keeping humans in the loop—making sure that people, not algorithms, hold the final say in decisions that affect learners (U.S. Department of Education, 2023). Among the most exciting possibilities is formative assessment: AI can deliver feedback as students work, giving them guidance that would be impossible for a single teacher to provide at scale.

Automated essay scoring is a good case in point—it can lighten a teacher's workload considerably, yet if deployed carelessly it can also undermine the pedagogical goals it is supposed to serve. There is also a growing consensus that AI should not merely be something students encounter passively; they need to understand how it works, where it falls short, and how to engage with it critically (U.S. Department of Education, 2023). This makes it essential that educational AI systems be transparent in their reasoning, open to being overridden, and subject to audit—because a wrong algorithmic decision in a school setting can leave marks that last well beyond a single semester (U.S. Department of Education, 2023).

Getting there will require researchers to build AI tools that are rooted in educational theory and adapted to local contexts, while educators, policymakers, technology firms, and academics work together on shared standards that keep AI use safe, fair, and genuinely helpful. Put simply, education needs its own regulatory guardrails—ones that protect both students and teachers without stifling the innovation that makes AI worth pursuing in the first place (U.S. Department of Education, 2023).

To situate this analysis within current regulatory developments, we briefly outline the EU Artificial Intelligence Act (Regulation (EU) 2024/1689) (European Union, Regulation 1689/2024). The Act establishes a risk-based framework, prohibiting certain practices—including the use of systems to infer emotions in educational institutions—and classifying several educational uses as high-risk (e.g., AI for admissions/access decisions, evaluation of learning outcomes, placement/streaming, and test proctoring/monitoring).

High-risk systems must implement risk management, data and data-governance measures, transparency to deployers, human oversight, and accuracy/robustness/cybersecurity; the Act also introduces transparency duties for AI interactions and synthetic content.

For AIED, this implies that learner profiling, automated assessment, and exam proctoring typically fall under high-risk obligations and must be designed and deployed with compliance-by-design and meaningful human control.

This paper integrates insights from a systematic review of over 2,200 peer-reviewed publications on AI in education, drawing primarily from indexed databases (e.g., Scopus, Web of Science, ERIC). Inclusion criteria focused on works published post-2017 addressing empirical applications, theoretical models, and governance frameworks. Thematic coding enabled the extraction of four main domains of application. The review is complemented by an interpretive policy analysis grounded in legal and ethical instruments (e.g., EU AI Act, UNESCO Guidance).

Given the rapid pace of technological advancement and the growing adoption of AI tools in educational contexts, this manuscript integrates theoretical foundations, current applications, and policy recommendations aimed at ensuring the responsible, equitable, and pedagogically grounded use of AI in education.

By synthesizing findings from recent research and international policy guidelines, it offers a solid foundation for future decision-making in educational technology and serves as a resource for teachers, researchers, and policymakers seeking to integrate AI meaningfully, ethically, and effectively into practice.

Foundations and conceptual framing of AI in education

AI is now woven into almost every corner of digital life, yet its importance for education runs deeper than hardware and code—it raises fundamental questions about how we construct knowledge, how we ought to teach, and how we can fairly judge what students have learned.

This section lays out the theoretical groundwork for AIED, sketches the field's intellectual architecture, and traces the main lines of thinking that inform how practitioners and scholars make sense of AI in schools and universities today.

What Counts as AI in Educational Practice?

In the scholarly record, AI is typically portrayed as a broad family of computational systems that exhibit capacities we associate with human cognition—learning from experience, reasoning through problems, perceiving their environment, and processing language. Alongside these conceptual descriptions sit more operational definitions stressing that such systems pursue predefined objectives either through rule-based logic or by learning patterns from data (U.S. Department of Education, 2023), (IEEE-USA Board of Directors, 2017). For educators, these are not merely academic distinctions: AI now routinely steps into roles that teachers used to fill on their own—selecting readings, adjusting the difficulty of a test, or even assigning marks (Friedman et al., 2021).

Narrow vs. General Intelligence: Implications for Teaching and Learning

The AI tools that actually show up in classrooms today are overwhelmingly "narrow"—each one built for a specific job, whether that means an expert system that scores quizzes, a neural network that recommends reading material, or a learning-analytics agent that tracks how students are progressing (Gartner, 2025). The idea of "general" AI—a system that could handle any intellectual task a human can—opens up even weightier ethical territory for education, particularly around empathy and care. Today's AI cannot forge the emotional connections with students that lie at the heart of good, relationship-driven teaching (The White House, 2022).

Models, Data, and Decisions: Why the Architecture Matters

At the technical core of every AI application is a model: a mathematical abstraction that takes in data and generates outputs—a usage of the word "model" quite different from how educators speak of pedagogical or institutional models (Ivković, 2025). Large language models like GPT embody this principle, working by predicting each successive word (or token) within enormous, high-dimensional parameter spaces. A key open question for the field is whether these statistical constructs capture enough of what actually matters in real classrooms. If a model's training data skew toward certain populations or contexts, the resulting system can discriminate in ways that hurt the very students it is meant to help. A robust framework for responsible AIED therefore requires explicit understanding of model assumptions and limitations.

Learning Theories as Design Anchors for AIED

AI-powered learning environments tend to be most effective—and most defensible—when they are rooted in well-tested learning theories. Constructivism is the framework cited most often, though researchers also draw on cognitive-load theory, item-response theory, and learning-styles accounts when designing personalized content and assessments. Intelligent Tutoring Systems are a good illustration: they diagnose individual learner needs and adjust pacing, feedback, and materials accordingly, going well beyond rote content delivery to offer support that is genuinely informed by pedagogical theory.

Augmented Intelligence: Partnering Humans and Machines

Current thinking in the field does not cast AI as a replacement for teachers but rather as a collaborator—a form of augmented intelligence that amplifies what human educators can do. In day-to-day terms, this looks like handing off repetitive chores—sending reminders, marking low-stakes quizzes—to AI, freeing teachers to spend more time on the creative, relational, and interpretive parts of their work. Critically, the teacher must always be able to inspect, question, and overrule whatever the system produces. The overarching idea is straightforward: AI ought to function as an ally in the learning process, not as an opaque arbiter whose verdicts cannot be challenged.

Mapping aied in practice: A four-domain typology

AI has moved well past the stage of being an occasional classroom novelty; it is now built into the routines and decision structures of education systems around the globe. Recent scholarship tends to organize these applications into four clusters: adaptive learning and individualized tutoring; intelligent assessment and classroom management; student profiling paired with predictive analytics; and newer AI-driven products that push the boundaries of what educational technology can look like. This typology is useful not only for comparing what each tool does, but also for thinking about the distinct pedagogical possibilities and trade-offs each category brings.

Personalized Adaptation: Intelligent Tutors & Hypermedia

At its core, AI-driven tutoring is about meeting each student where they are—adjusting what they see, how fast they move, and what feedback they receive. Intelligent Tutoring Systems (ITS) function much like attentive mentors: they watch what a student does, infer what help is needed, and steer the learning path accordingly. ZOSMAT, a mathematics-focused system that pairs learning analytics with individualized navigation, is one well-documented example. Common features of such systems include diagnostic quizzes that pinpoint gaps, practice exercises calibrated to each learner's level, and reading or activity suggestions that match demonstrated competence. A complementary line of work, Adaptive Hypermedia Learning Systems (AHLS), adapts presentation and sequencing to students' learning preferences using methods like neural networks and Bayesian classifiers—advancing the ideal of "education to the learner," with self-paced progression matched to ability and interest.

Assessment and Orchestration: AI-Enabled Evaluation & LMS

Providing personalized attention to every student is hard enough in a single classroom; at institutional scale, it becomes all but impossible without automated support—hence the growing role of AI in assessment and classroom management. Intelligent assessment platforms handle tasks like scoring, competency mapping, and ongoing formative tracking—MI Write, for instance, evaluates student essays—while specialized pronunciation trainers offer detailed, immediate feedback on spoken language. Alongside these tools, learning management systems enhanced with AI consolidate student data, take over repetitive administrative work, and flag issues that instructors might otherwise miss. Typical capabilities comprise collaborative learning support, exam and evaluation workflows, and resource management with content recommendations; AI's role within these platforms is increasingly pivotal for observing progress and orchestrating timely interventions.

Learner Trajectories: Profiling & Predictive Modeling

A third major area of AI application brings together educational data mining and learning analytics to build profiles of individual learners and forecast their academic trajectories. Algorithms—Naive Bayes classifiers, neural networks, decision trees, support vector machines, among others—sift through behavioral data to estimate which students are academically at risk and how they are likely to perform. In practice, these systems generate early alerts about potential dropouts, predict grades and completion rates, model patterns of student behavior, and help advisors guide course selection. These predictive pipelines are already used to anticipate course selection or satisfaction, enabling administrators to align programs with learner needs and to advance precision education through proactive support.

Novel Interfaces: Robots, XR, and Generative Systems

Some of the most visible innovation in AIED comes from robotics, extended reality (VR and AR), and generative AI. Educational robots—many of them chatbot-driven—take on roles as varied as co-teacher, study buddy, emotional-support companion, and telepresence proxy for students who cannot be physically present. Published examples range from toy robots that help children practice Chinese idioms to conversational bots that facilitate book-club discussions. Virtual and augmented reality add another dimension, placing students inside immersive simulations—virtual labs, historical reconstructions—that can boost both engagement and experiential understanding. Meanwhile, generative tools such as ChatGPT open up possibilities for essay drafting, conversational tutoring, and the collaborative creation of learning materials—pushing AIED beyond its traditional focus on content delivery and assessment feedback.

Table 1 maps the principal AIED application domains onto the risk categories set out in the EU Artificial Intelligence Act (2024), offering a bird's-eye view of where each type of tool sits in the regulatory landscape. Because the impact on learners and educational outcomes differs substantially from one domain to another—adaptive learning environments carry different risks than, say, generative AI chatbots—so too do the levels of regulatory scrutiny that apply. The high-risk tier is especially pertinent for automated grading, student profiling, and decisions about who gets access to educational opportunities; here the Act requires stringent safeguards—transparency, auditability, human oversight, and verified data quality. Reading the table from left to right gives practitioners a way to weigh both the pedagogical promise and the compliance burden of different AI deployments in their own institutional context.

Table 1. *Mapping AIED Domains Against EU AI Act Risk Categories and Regulatory Obligations*

AIED Application Domain	Examples of Tools / Functions	Theoretical Foundation	Risk Classification (EU AI Act)	Regulatory Obligations
1. Adaptive Learning and Personalized Tutoring	Intelligent Tutoring Systems (ITS), Adaptive Hypermedia Systems (e.g., ZOSMAT)	Constructivism, Cognitive Learning Theories	Limited / High Risk (depending on their impact on learner evaluation or progression)	Transparency to users- Human oversight- Risk assessment (if affecting learner access or progression)
2. Intelligent Assessment and Learning Manag.	Automated essay scoring (e.g., MI Write), AI- enhanced LMS platforms, E-proctoring tools	Assessment theory, Constructivist Pedagogy	High Risk (especially for automated grading, test proctoring, and evaluation systems)	Risk management systems- High-quality datasets- Meaningful human control- Incident reporting mechanisms
3. Learner Profiling and Predictive Modeling	Dropout prediction, performance forecasting, behavioral analytics	Learning Analytics, Data-Driven Instruction	High Risk (when influencing educational decisions through profiling or prediction)	Bias testing and documentation- Auditability- Explainability of decisions- Right to human review
4. Innovative AI Tools: Robotics, XR, Gen. AI	ChatGPT, educational robots, VR/AR for immersive learning	Constructivism, Experiential Learning	Limited / Minimal Risk (if not involved in decision-making or profiling)	Disclosure of AI-generated content- Notification of AI interaction- Integration of AI literacy in curricula

Governance and action agenda for trustworthy aied

As AI spreads through every level of education, the policy conversation has shifted from whether it should be governed to how, precisely, to go about doing so. These are no longer speculative technologies; they are tools that teachers and students encounter every day—automated grading, adaptive tutoring, predictive analytics—and they carry genuine opportunities for better learning alongside real worries about fairness, privacy, accountability, and the preservation of human agency. Building a coherent policy architecture that speaks directly to education's needs is therefore urgent if we want AI to be deployed safely, equitably, and to genuine effect.

Human-in-the-Loop and Pedagogical Sovereignty

The starting point for any sensible policy is that AI should strengthen human judgment, not supplant it. Regulations should insist that AI systems used in schools be explainable, auditable, and capable of being overridden—so that teachers, students, and administrators can grasp what the system is recommending, check whether that recommendation makes sense, and set it aside when it does not. Preserving this kind of control is what keeps pedagogical sovereignty intact: educators must be free to step in whenever an AI output clashes with what they know about their students or the realities of their classroom (U.S. Department of Education, 2023).

Equity by Design: Bias, Fairness, Inclusion

Equity in digital education is not a nice-to-have; it is a baseline requirement. Models trained on data that underrepresent certain groups risk replicating—and even amplifying—existing structural injustices. Policy should therefore require concrete safeguards: routine checks on data quality, independent fairness testing, and the active involvement of diverse stakeholders at every stage of design and evaluation, all aimed at preventing AI from disproportionately harming the very students who most need support (The White House, 2022).

Pedagogy-First Alignment of AI Tools

Educational AI ought to be grounded in pedagogical theory and designed to foster active, experience-based, constructivist learning—not mere drill-and-recall. Close partnerships between tool developers, classroom teachers, and educational researchers are vital if the resulting products are to address genuine learning needs across different student populations. In other words, policy needs to keep AI firmly tethered to well-founded pedagogical ideas and established learning science (European Commission, DG EAC, 2022).

Data Governance and Radical Transparency

Educational AI runs on vast quantities of sensitive information—behavioral traces, interaction logs, grades, sometimes even socioeconomic background data—which means governance frameworks must enshrine strong privacy safeguards (like FERPA compliance), along with anonymization protocols, strict access controls, and disciplined rules for data sharing. Institutions must tell students and families plainly what data are being gathered, why, and how those data feed into decisions—and obtaining informed consent while shielding sensitive personal attributes is not optional (U.S. Department of Education, 2023).

Capacity Building and AI Literacy for Educators

Ironically, the people who deal with AI in classrooms most directly—teachers—are often the ones with the least training and support for doing so effectively. Mandatory professional development and AI-literacy initiatives should give teachers the skills to use these tools with confidence, read their outputs critically, and step in when something goes wrong. Policymakers, for their part, need to back up those programs with practical resources and everyday guidance on how to weave AI responsibly into regular teaching (IEEE-USA Board of Directors, 2017).

Participatory Policy and Co-Design with Stakeholders

Governance becomes more credible when the people affected by it have a hand in shaping it. That means bringing students, parents, teachers, school leaders, and technology companies together to co-develop guidelines—ensuring that the tools deployed in schools genuinely reflect the educational and human values of the communities they serve. When communities are involved, the result is more likely to respect local languages, cultures, and priorities—which in turn makes the technology more relevant and its governance more just.

National Frameworks and EU Guidance for Education

Individual institutional policies are not enough; countries need dedicated regulatory frameworks for education that set minimum technical and ethical standards, require impact assessments across different student groups, evaluate how AI affects both staff and learners, and mandate ongoing monitoring of live systems. As a reference point, the European Commission's educator-focused Ethical guidelines on the use of AI and data in teaching and learning offer a useful model for sectoral governance (Maslej et al., 2023). Legal scholarship further underscores alignment with constitutional guarantees and international norms on digital rights and the right to education.

Weaving these normative commitments directly into the fabric of policy does more than ensure legal compliance—it lends the whole enterprise a measure of ethical credibility that purely technical standards cannot provide.

The EU AI Act (2024) and education

This chapter interprets the EU Artificial Intelligence Act (2024), arguing that the Act's risk-based architecture, graduated obligations, and governance innovations provide both a regulatory compass and a practical playbook for educational actors deploying adaptive systems and assessment technologies at scale; yet, translating that framework into classroom-ready practice will require sustained alignment with international pedagogical guidance, robust cybersecurity preparedness, and institution-level capacity building.

At the core of the AI Act is a four-tier risk taxonomy—unacceptable, high, limited, and minimal/no risk—that calibrates obligations according to anticipated harms and the salience of fundamental rights in context; crucially for education, the Act explicitly positions certain uses (e.g., scoring of exams, systems that shape access to education) within the high-risk category, thereby elevating educational assessment and learner-profiling beyond mere ed-tech functionality to the domain of regulated socio-technical systems with mandatory risk management, high-quality datasets, traceability/logging, human oversight, and demonstrable levels of robustness, cybersecurity, and accuracy (European Commission, 2025), (European Parliament, 2025).

In parallel, the Act enumerates a closed list of prohibited practices, including emotion recognition in educational institutions, social scoring, and untargeted scraping for facial recognition databases, which directly constrains a swath of speculative "affective computing" and invasive monitoring tools sometimes marketed to schools; for educators and administrators, this prohibition line clarifies not only what cannot be procured or piloted, but also how to frame vendor due diligence and contract clauses ex ante so that "innovation" initiatives do not drift into rights-eroding experimentation (European Commission, 2025).

The Act's transparency layer further touches classroom realities: interactions with AI must be disclosed, AI-generated content must be identifiable, and deepfakes or other synthetic media intended to inform the public require clear labeling—obligations that intersect with academic integrity policies, media literacy curricula, and institutional rules on the acceptable use of generative models in teaching and assessment (European Commission, 2025), (European Parliament, 2025). For general-purpose AI (GPAI) models—the engines increasingly powering adaptive learning platforms, automated feedback tools, and content generators—the AI Act introduces targeted obligations (e.g., transparency on training data via public summaries, copyright compliance, risk assessment and mitigation for models with systemic risk), complemented by Commission guidance and a Code of Practice to smooth compliance pathways while the regime matures; these GPAI rules matter for schools precisely because they externalize upstream model accountability, making it more feasible for deployers (schools, universities, ministries) to rely on contractually enforceable representations about model safety, security, and data provenance (European Commission, 2025).

The timeline also conditions sectoral planning: the Act entered into force on 1 August 2024, with prohibitions (and AI-literacy duties) applicable from 2 February 2025, GPAI obligations applicable from 2 August 2025, full applicability slated for 2 August 2026, and extended deadlines (e.g., certain high-risk systems embedded in regulated products) out to 2 August 2027—sequencing that allows ministries and institutions to schedule gap assessments, budget cycles, and teacher professional development in step with legal milestones (European Commission, 2025), (European Parliament, 2025). Read normatively, the AI Act reframes adaptive systems from a narrow narrative of hyper-personalization and efficiency into a governed pedagogy of adaptation: personalisation remains legitimate when underwritten by explainability, contestability, and documented human oversight; dataset quality is not a technical nicety but a legal duty; and learning analytics pipelines become subject to post-market monitoring in which serious incidents (e.g., systemic misgrading, biased placement recommendations) can trigger reporting and corrective action (European Commission, 2025), (European Parliament, 2025).

For assessment, the implications are even more direct: automated scoring, proctoring, and predictive risk flagging now sit within a compliance perimeter where model-risk analysis, bias testing, robustness to adversarial inputs, and audit-ready documentation are not optional; in practice, this encourages assessment designs that pair algorithmic scoring with calibrated human adjudication ("human-in-the-loop"), set clear escalation protocols for edge cases, and publish intelligible grading rationales to preserve due process for students (European Commission, 2025), (European Parliament, 2025).

Because risk classification is the linchpin on which obligations hang, education policymakers can profitably integrate the OECD Framework for the Classification of AI Systems into their institutional risk triage: mapping an AI system along the framework's dimensions—People & Planet, Economic Context, Data & Input, AI Model, Task & Output—helps expose where a given adaptive tutor or proctoring tool implicates fundamental rights (e.g., equality in access), what data flows create privacy and representativeness risks, which model characteristics stress explainability, and how task-output couplings might enable or foreclose pedagogically sound override mechanisms; the OECD framework's lifecycle orientation (planning/design; data collection; model building/validation; deployment and monitoring) dovetails with the Act's demands for pre-market conformity assessment and post-market vigilance, offering a shared vocabulary by which school systems, vendors, and regulators can align on evidence of safety and accountability (OECD, 2022).

In domains where generative AI becomes a co-author of learning artefacts (lesson plans, formative feedback, worked examples), UNESCO's global Guidance for Generative AI in Education and Research supplies a concrete programmatic complement to the Act's legal minimalism: beyond compliance, UNESCO calls for age-appropriate guardrails, teacher-led validation workflows, and explicit curricular integration of AI literacy to sustain a human-centered, rights-preserving adoption; taken together, the UNESCO guidance and the AI Act suggest that the legitimate pedagogical uses of GPAI are those that preserve human agency, embed privacy-by-design, and make the limits of model knowledge visible to learners (Miao and Holmes, 2023).

Notably, the AI Act's emphasis on robustness, cybersecurity, and accuracy is not decorative: the ENISA Threat Landscape underscores that ransomware, DDoS, phishing, and related attacks remain persistent and adaptive, while AI-enabled threats (e.g., automated phishing, synthetic-voice fraud, data exfiltration targeting model pipelines) complicate institutional risk profiles; in education settings—where networks carry sensitive learner data and assessment systems may present tempting extortion targets—the Act's requirements for logging, incident reporting, and resilience should translate into concrete procurement clauses (e.g., secure model-update channels, adversarial-robustness testing, rate-limiting and anomaly detection) and operational controls (e.g., separation of duties, recovery plans, red-team exercises) commensurate with the sector's exposure (European Commission, 2025), (ENISA, 2024).

On governance, the Act's distributed architecture—European AI Office, national market-surveillance authorities, AI Board and advisory bodies—creates escalation and coordination pathways likely to affect education in three ways: first, by generating codes of practice and interpretive guidance that lower transaction costs for small ministries and school networks; second, by standardizing registries and documentation templates that enable comparability of high-risk deployments (e.g., exam-scoring engines); and third, by anchoring enforcement in administrative routines that encourage continuous improvement (e.g., corrective action plans, proportional penalties) rather than one-off punitive gestures (European Commission, 2025), (European Parliament, 2025). Strategically, aligning adaptive learning with the Act means institutionalizing a pedagogy-first compliance culture:

- needs analysis and theory-of-change before tool selection;
- explainability criteria tied to specific learner decisions (placement, feedback, progression);
- calibration studies that check algorithmic recommendations against expert judgments across student subgroups;
- a duty to furnish students with recourse, including the right to a human review of impactful automated decisions (European Commission, 2025), (OECD, 2022).

For assessment, the combination of transparency duties and high-risk obligations invites renewed attention to validity and fairness: if a proctoring classifier generates false positives differentially by lighting, skin tone, or disability status, then both the Act's dataset-quality requirement and equity commitments in education policy are implicated, compelling iterative retraining, alternative accommodations, or—where irreparable—retirement of the system; conversely, where automated scoring aids formative feedback without deciding high-stakes outcomes, limited-risk transparency may suffice, provided institutions clearly signal to learners when AI is involved and how its suggestions are moderated by instructors (European Commission, 2025), (European Parliament, 2025), (Miao and Holmes, 2023).

Finally, the chapter contends that responsible governance post-Act is a project of institutional capability as much as legal conformity: ministries and universities should inventory AI-mediated decisions, classify them using OECD criteria, decide—policy-by-policy—where high-risk thresholds are crossed, and build UNESCO-aligned AI literacy into teacher education and student orientation; procurement should prefer vendors who evidence adherence to GPAI guidance, publish training-data summaries, and support auditability; and CISOs should plan for ENISA-profiled threats with controls that map to the Act's robustness and post-market monitoring obligations; done well, the result is not compliance theatre but a defensible, learner-first operationalization of the Act's animating principle: trustworthy AI in education that enhances learning while protecting rights (European Commission, 2025), (ENISA, 2024).

While this paper outlines foundational principles for responsible AIED, further empirical research is needed to evaluate real-world impacts across diverse educational systems. Future work should investigate longitudinal learning outcomes, the effectiveness of human-in-the-loop models, and equity effects of algorithmic interventions. Policymakers should prioritize capacity-building and iterative evaluation as core components of AI adoption in education.

Conclusion

Education is changing rapidly, and AI is one of its most powerful catalysts—but it is far from a neutral instrument, and deploying it responsibly demands sustained attention to ethical, pedagogical, and legal standards. This paper has assembled a framework that weaves together theory, real-world applications, and regulatory alignment, foregrounding the roles of human agency, sound data governance, and transparency at every turn. With the EU AI Act now redefining the ground rules for how adaptive systems and automated assessments can be designed and deployed, educators and policymakers face both an obligation and a rare opportunity to shape a pedagogy that embraces innovation without abandoning its responsibilities. Going forward, what the field needs most is empirical work—studies that evaluate these systems across different institutional contexts, with a persistent focus on whether they actually promote equity and whether the institutions using them are ready for the challenge.

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Signature as a Trace of Identity: A Theoretical - Research Approach to Criminal Profiling

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Abstract: This paper examines the concept of the signature in criminal profiling as a key indicator that reveals the offender's psychological structure and internal motivation. Unlike the modus operandi - which includes the technical and functional aspects of committing a crime - the signature reflects the offender's emotional and psychological needs that extend beyond the purpose of the act itself. The signature is viewed as an expression of inner impulses and fantasies, manifested through stable behavioral patterns and rituals. The research emphasizes its applicability in contemporary profiling, particularly in the identification of serial offenders, where stable signature elements allow investigators to connect cases that initially appear unrelated. However, a signature is not always present - it may be absent due to situational factors, emotional fluctuations, or deliberate concealment of trace evidence. The examination of real investigative cases, along with examples from literature and film, shows that identifying the offender's signature behavior helps investigators better understand the motives that drive the crime. Once the signature is recognized, it provides deeper insight into the offender's internal impulses, making it easier to connect related crimes and contributing to their eventual resolution.

Keywords: *signature, modus operandi, criminal profiling, forensic psychology, serial crimes.*

Introduction

In crime novels, films, and television series, serial killers often leave distinctive traces - known as *signatures* - that reveal their unique psychology and personal style of offending. For example, in the 1980 film *Maniac*, the killer scalps his victims and uses their hair to decorate mannequins. Similarly, Buffalo Bill from the 1991 film *The Silence of the Lambs* places moths inside the throats of his victims as part of a symbolic ritual. In Dan Brown's *Angels and Demons*, the murderer brands symbols representing the four natural elements onto the bodies of his victims. In *Seven*, the character portrayed by Kevin Spacey stages murders inspired by the seven deadly sins, while in the series *True Detective*, the killer places crowns made of deer antlers on the victims' heads, creating a disturbing visual *signature*. In the series *Dexter*, the protagonist Dexter Morgan directs his homicidal urges toward criminals who have escaped justice. Immediately before killing, he collects a personal trophy to relive the experience later. His distinctive ritual *signature* involves making a precise cut on the victim's cheek with a scalpel - usually while the victim is still alive, though sometimes post-mortem - just below the right eye. He then places a drop of blood between two microscope slides. These slides are neatly arranged in a wooden storage box hidden inside his air-conditioning unit (Bjelajac, 2025: 267–268). Patrick Bateman, the protagonist of *American Psycho*, represents the archetype of a double identity: outwardly a successful and charming businessman, he hides a deeply disturbed murderer beneath the surface. His luxurious lifestyle allows him to carry out his crimes unnoticed. The bodies of his victims display precise, ritualistic marks, revealing his obsessive need for control, the aestheticization of violence, and compulsive behavior driven by narcissistic and antisocial personality traits.

In real life, serial killers are often far less imaginative than the versions portrayed in Hollywood.

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Their crimes are not shaped by cinematic spectacle, but by recognizable behavioral patterns known to experts as *modus operandi* (MO) and the killer's *signature*. The *modus operandi* describes what the offender must do in order to commit the crime. This pattern may change depending on circumstances. For example, Dennis Rader, known as the *BTK Killer*, murdered most of his victims by strangulation and asphyxiation, yet in several cases he killed differently, including by hanging or stabbing. The *signature*, on the other hand, represents the killer's personal imprint - an element that fulfills emotional and psychological needs. It includes rituals, patterns, and actions that reflect the killer's deep fantasies about his victims (Bjelajac, 2025: 269). Unlike the *modus operandi*, the *signature* is stable and persistent over time and rarely changes. It is often formed long before the first murder, as a result of early psychological impulses and pathological experiences. This development can be seen in the case of Dennis Rader, who as a child displayed sadistic tendencies by torturing and killing animals - behaviors that later evolved into his recognizable *signature* in serial offenses.

Linking crimes has become a subject of growing attention in academic research. Studies have provided support for the principles of behavioral consistency and distinctiveness, which form the foundation of crime linkage (Davies and Woodhams, 2019). The most notorious serial killers simultaneously evoke horror, curiosity, and fascination, because they reveal how deeply human nature can descend into darkness and distortion. Their ability to live for years among ordinary people - appearing as neighbors, friends, churchgoers, parents, or spouses - while simultaneously leading a double life as cold-blooded murderers, demonstrates how thin the boundary between normality and pathology can be. Many of them operated unnoticed, hiding their monstrous impulses behind the mask of social acceptance. When the truth eventually surfaced, the shock was immense - precisely because those who seemed the most ordinary became symbols of human depravity. Today, with a deeper understanding of criminal psychology, we recognize that these offenders are human beings as well, but individuals who, at some point in their lives, abandoned moral and legal boundaries and stepped into the depths of their own darkness.

Generally speaking, a violent serial offender often displays one defining element of criminal behavior during the commission of a crime: his *signature*, that is, a recognizable personal imprint expressed through actions that go beyond what is necessary to complete the offense - *modus operandi* - and reveal the offender's unique psychological makeup. Unlike the MO, the offender's *signature* does not change in its core. Certain details may evolve or become more refined over time (for example, a lust killer may engage in increasingly intense post-mortem mutilation as he progresses from one crime to the next), but the fundamental aspect of the *signature* remains constant (in this case, the performance of post-mortem mutilations) (Douglas and Douglas, 2006). What constitutes such a *signature*? Surviving victims or witnesses may sometimes testify about behavioral components of the *signature*. For instance, a rapist may reveal his *signature* behavior through displays of domination, manipulation, or control during the verbal, physical, or sexual phase of the assault. Extremely vulgar or degrading language, as well as insisting on a specific script or scenario, represents a verbal *signature*. When the offender *scripts* the victim, he demands a particular verbal response (e.g., "*tell me how much you enjoy this*," or "*tell me how good I am*"). A rapist may also follow his own internal script by performing a sequence of sexual acts with different victims in the same predetermined order (Douglas and Douglas, 2006). These victims are very often women involved in prostitution, whom the offender perceives as accessible targets lacking social protection and suitable for acting out his deviant fantasies (Bjelajac, 2011).

The aim of this research is to examine in detail the theoretical and practical aspects of the *signature* as one of the key indicators in contemporary criminal profiling. Special emphasis is placed on the psychological, emotional, and forensic dimensions of the *signature*, as well as on its role in differentiating serial crimes and identifying offenders. The study explores the *signature* as an expression of the offender's internal needs, its relationship to motive and *modus operandi*, and the conditions under which the *signature* may be altered, concealed, or completely absent. Furthermore, the objective is to clarify the functional role of *signature* behavior in the profiling process through a research-based perspective supported by practical examples (both real and fictional cases). Additionally, the paper aims to provide a concise overview of activities that constitute *signature* behavior and to highlight its significance in accurately linking and profiling serial offenders.

Based on the defined objectives, the research questions were formulated to address the key features and recognizable characteristics of the *signature* in criminal investigation practice, its fundamental principles and elements in the profiling process, as well as the challenges that arise during its application in investigative procedures: how the *signature* manifests as a key indicator in criminal profiling; in what way the *signature* reflects the offender's internal psychological and emotional needs; what the essential differences are between *modus operandi* and *signature* behavior in terms of function and interpretation; how the *signature* may shift across different stages of criminal behavior and under which circumstances it may be absent; which factors contribute to the lack of *signature* in certain offenses, including the offender's emotional state, situational conditions, or previous experience; to what extent monitoring *signature* behavior improves the accuracy of profiling and the identification of serial offenders; and how examining concrete examples of *signature* behavior can contribute to advancing profiling methodology; and how research insights related to the *signature* can be applied in contemporary forensic and law-enforcement practice. In line with the above, the following hypotheses were formulated: the *signature* represents a stable and recognizable behavioral pattern that reflects the offender's deep psychological and emotional needs; there is a clear distinction between *modus operandi* and *signature*, with the *signature* expressing internal motives, fantasies, and psychological impulses, whereas *modus operandi* has a functional and operational purpose; *signature* analysis holds significant diagnostic and identification value in criminal profiling, as it enables recognition of stable and recurring behavioral patterns; the *signature* is not present in every crime, and its absence is related to situational factors, emotional instability, or deliberate concealment of traces; the analysis of concrete cases in which distinctive *signature* behavior appears shows that correctly identifying this pattern facilitates linking multiple crimes committed by the same offender and enables more accurate profiling; in addition, portrayals of serial crimes in popular culture and crime television series have contributed to the wider understanding of this concept and have brought it closer to the general public, although simplifying the profiling process, contribute to the understanding and popularization of the *signature* concept in both public and academic domains.

Methodology

The research is based on a qualitative - comparative and descriptive–analytical approach, aimed at thoroughly examining the *signature* as a psychological-forensic indicator within the criminal profiling process. The study includes an analysis of relevant scientific and professional literature in the fields of criminology, forensic psychology, and behavioral analytics, as well as empirical examples of real cases and their representations in popular culture and crime television series. The methodological framework involves identifying and classifying forms of *signature* behavior, comparing them with *modus operandi* to determine similarities and differences, and analyzing the conditions under which the *signature* evolves, changes, or disappears. Special emphasis is placed on evaluating the forensic and psychological value of the *signature* in the profiling process and its significance for identifying serial offenders. The obtained results are analyzed descriptively and interpretatively, with the aim of confirming or refuting the proposed hypotheses and highlighting practical implications and possibilities for applying the *signature* concept in contemporary investigative practice and criminal analytics.

Signature as an Expression of the Offender's Inner Needs

"Several women - eleven victims in total - were murdered in separate incidents in the Whitechapel district of London between 1888 and 1891. Analysis of these homicides showed that six of the cases were linked through a series of specific and personal *signature* characteristics, including picquerism (pleasure derived from stabbing with a sharp object), excessive use of force (overkill), victim incapacitation, domination and control, displaying the body in an exposed location, unusual body positioning, sexual degradation, mutilation, organ removal, targeting specific body areas, preplanning and organization, as well as the presence of multiple combined *signature* traits" (Keppel, Weis, Brown, and Welch, 2005). *Overkill* is characterized by the presence of excessive or repetitive wounds inflicted on the victim's body (Tavone et al., 2022; Baldari et al., 2024). Such behavioral patterns indicate a deeply rooted psychopathological need of the offender to express control, power, and ritualized symbolism through the act of violence, transforming the crime from a purely physical event into a manifestation of an internal psychological construct.

The signature aspect of a violent offender represents an integral and unique component of their behavior (Geberth, 1995, p. 45). A *signature* may be described as a personal stamp or a unique behavioral pattern; it is defined as a distinctive combination of actions that becomes observable across two or more crimes (Hazelwood and Warren, 2003, p. 591; Keppel and Birnes, 1997, pp. 2–3). According to several authors (Bartol and Bartol, 2005, p. 327; Douglas and Munn, 1992, p. 3; Hickey, 2002, pp. 124–125*)*, *the signature* represents a part of the offender's behavior that is not necessary for committing the crime, yet carries a distinct personal imprint. Unlike actions that are functionally required to complete the offense, the *signature* reflects the offender's internal psychological needs and emotional motives. It stems from fantasies and ideas that have been developed in the offender's mind over time, with the crime serving as the means through which those fantasies are finally enacted. When the offender acts on what was previously imagined, certain details at the crime scene reveal elements of his identity - a ritual, gesture, or symbol with personal meaning that distinguishes him from other perpetrators. Through this ritual, the offender leaves part of their personality at the crime scene. This becomes evident through specific characteristics of the scene or through unique actions carried out during the crime. The offender's *signature* is not necessarily tied solely to internal fantasy. It may manifest in various forms, but it is broadly understood as the offender's personal trace (Hickey, 2006, p. 103). The *signature* does not exclusively represent fantasy - it can also reflect a complex expression of psychological needs, emotional impulses, and the need for control. It manifests as a subtle yet persistent mark of the offender's individuality, revealing how the offender perceives themselves, the victim, and the act of the crime itself.

The *signature refers to a specific pattern of behavior that reveals the offender's underlying psychological and emotional drives*. In offender profiling theory, two levels of this concept are distinguished: the *conceptual component* and the *behavioral manifestation*. The conceptual component reflects the motivational background - the emotions, needs, or fantasies that the offender seeks to satisfy through the crime. The behavioral manifestation consists of concrete actions at the crime scene that are not necessary to commit the offense, but clearly express the offender's internal motivation (Douglas et al., 1992, p. 261; Turvey, 2003, pp. 279–281; Savino and Turvey, 2005, pp. 270–271). These behaviors serve as a unique imprint of the offender's personality, exposing underlying motivations and illustrating how the offender perceives the criminal act.

Keppel (2000) points out that, in practice, offender *signature* is frequently mistaken for *modus operandi*, despite the clear conceptual distinction between the two. The *modus operandi* refers to the actions that are necessary for carrying out the crime - such as the method of entry, controlling the victim, or escaping the crime scene. This pattern may evolve over time, as the offender gains experience, learns from mistakes, and adapts tactics to new circumstances. The *signature*, on the other hand, does not depend on situational factors and does not change for practical reasons. It reflects the offender's internal world - his fantasies, obsessions, and psychological needs. Because of this, the *signature* is far more stable: while the technical aspects of a crime may change, the underlying emotional motive remains constant. Offenders who exhibit *signature* behavior are not satisfied with merely completing the criminal act. They feel compelled to leave a trace that carries personal meaning. What previously existed only in fantasy - imagined scenarios repeatedly rehearsed in the mind - becomes real during the crime, expressed through a specific action, object, symbol, or ritual (Keppel and Birnes, 1997, pp. 4–5; Keppel, 1995; Keppel, 2000). In that moment, what once existed only in his imagination shifts into concrete action and takes on a real form through the crime.

"It is important to emphasize that crime scenes and offender behavior are never completely identical across different offenses, even when committed by the same perpetrator. Victims may respond differently, which can influence the offender's reactions, and the locations of the crimes often vary as well - all of which can affect the offender's behavior. The mere repetition of certain actions across multiple offenses does not in itself constitute a *signature.* In general, *signature* behavior requires additional time beyond what is necessary to carry out the functional elements of *the modus operandi*. It is not essential for completing the crime and may involve the expression of emotions and/or fantasies" (Savino and Turvey, 2005, pp. 272–273). Through this, *the signature* becomes an expression of the offender's internal need to assign personal meaning to the crime, beyond its functional execution.

Research Perspective and Application of the Signature Aspect

A characteristic aspect of a violent offender is a unique and integral part of their behavior. This *signature component* refers to the psychodynamics - the mental and emotional motivation behind the act. Although human behavior is unpredictable, it often exhibits repetitive patterns. Research has shown that certain actions performed by particular personality types at a crime scene tend to reoccur in other homicide investigations (Geberth, 1995). A criminal investigator specializing in homicide cases, who has enriched their professional experience with a deep understanding of the psychodynamics of human behavior, gains the ability to build a comprehensive framework of knowledge. This framework not only enables the investigator to perceive behavioral patterns and psychological motives of offenders but also to effectively apply the acquired knowledge in analyzing and comparing similar cases (Bjelajac, 2025: 274–275; Bjelajac, 2022; Bjelajac, 2024). Such insight provides the investigator with the ability to identify hidden patterns and connections among crimes that may initially appear unrelated, to recognize consistent elements in offender behavior, and, based on that, to develop more effective strategies that enhance the course of investigations and the resolution of complex criminal cases.

From a research perspective, it is important to note that these individualistic behaviors are learned behaviors that tend to remain consistent over time. The offender's MO *(modus operandi)*, or method of operation, is also a learned behavior. However, such behaviors evolve as offenders gain experience, build confidence, or become involved with the criminal justice system. *The signature component* may also change to some extent; however, such changes usually involve an escalation in violence and sexual mutilation, consistent with paraphilic sexual sadism often observed in lust murders. The MO encompasses the actions necessary to carry out the crime, while the *signature* aspect represents the offender's underlying emotional needs. These needs are typically expressed through behaviors and actions that go beyond what is necessary to complete the criminal act. When dealing with an offender who is a sexual sadist, an escalation of violence can be expected as the series of crimes progresses (Geberth, 1995). Understanding and distinguishing between the *modus operandi* and *signature behavior* is of essential importance in criminal profiling, as it enables the investigator to recognize connections between seemingly unrelated crimes and to identify their common behavioral patterns. By synthesizing the technical aspects of the act with the psychological traces left by the offender, it becomes possible to reconstruct the offender's mindset, identify recurring behavioral patterns, and uncover the deeper motives that drive their actions.

Case History: Timothy Spencer	
Crimes	Timothy Spencer, who was responsible for the sexual murders of four women, was a *silent* burglar and rapist who stalked his victims. He was able to enter their homes while they were sleeping. In the crime he committed in Chesterfield County, he managed to gain access to a 15-year-old victim while her parents were sleeping in another part of the house. In the other three cases, he targeted women who were married or in relationships, attacking them in their own homes. He had complete control over these victims and spent a considerable amount of time in their homes. His behavior toward the victims and his actions at the crime scenes indicated that he was a classic sexual psychopath.
Signature	The pursuit of this offender was based on the *theory of crime signature*. In each of the incidents, the women were raped and sodomized by the attacker after he approached them in their sleep. Each victim was strangled to death by ligature. Each was found lying face down and in a similar manner - bound with their hands tied behind their backs.

Figure 1. Case History: Timothy Spencer (Geberth, 1995)

An example of a characteristic *signature* - behavior that goes beyond what is necessary to commit the crime - can be observed in the *Bethelsdorp Rape Case*. The victim was sleeping in her home when two offenders broke in. Both of them raped the victim. After the rape, one of the suspects took a stick and inserted it into the victim's vagina. This behavior is often regarded as an act that exceeds what is required to commit the crime. Both offenders had already completed penetration (raped the victim), but subsequently inserted the stick into her vagina, which under law constitutes an additional act of rape. The insertion of *foreign objects* is often considered a psychologically motivated behavior (Labuschagne and Theron, 2008:117). When actions appear at the crime scene that are not necessary for committing the offense, but instead carry the offender's personal message or meaning, this is considered a *signature*. Such behavior becomes recognizable through specific and repeated acts: a particular sequence of sexual activities, a characteristic method of binding, inflicting the same type of injury, deliberately positioning the victim's body in an unusual or shocking way, torturing or mutilating the victim, as well as performing a ritual that holds personal significance for the offender (Bjelajac, 2025: 277–278). These abnormal behaviors can sometimes be more easily detected through nonverbal patterns of communication - such as body posture, facial expressions, or controlled movements - which unconsciously reflect the offender's internal dynamics and latent psychological impulses (Bjelajac and Banović, 2024).

Case History: George Russell	
Crimes	A series of murders occurred in the state of Washington in 1990. The killings began in Bellevue, Washington, in June and ended in King County in September 1990. Initially, authorities were not aware of the connection between these cases due to delays in analyzing pubic hair evidence collected from the first two crime scenes. Furthermore, the investigation was misdirected when a more persistent suspect appeared in the second murder inquiry. However, once the hair evidence was analyzed and the initial suspect eliminated, authorities were presented with a classic series of *signature* - type events.
Signature	It is important to note that in the real world of conducting active homicide investigations, we do not have the luxury of *retrospective knowledge*. Many so-called *experts* who criticize police investigations become "smart after the fact," once ALL the information becomes available for review. When you look at this case chronologically and assess the information authorities had at the time of the investigation, it becomes clear how these cases initially did not appear to be connected.

Figure 2. *Case History: George Russell* (Geberth, 1995)

In the case of the *Vampire Killer (Law and Order, June 1991),* the murderer targeted young women whom he eviscerated. The investigation revealed that the perpetrator had removed the blood and body parts of his victims. Sexual motives were evident in the mutilations. Other activities of the offender were so absurd and bizarre that the authorities were immediately able to link the incidents. However, the motivation behind these crimes appeared completely irrational (Geberth, 1995). The criminal, who seemed utterly indifferent to the possibility of being caught, left numerous physical traces and pieces of evidence at the crime scenes. Investigators correctly directed the investigation toward an individual who could be characterized as *psychotic or disorganized*. Indeed, one of the most common *signatures* belongs to a *psychopathic sexual sadist*, whose primary trait is the desire for complete *domination over the victim* (Geberth, 1995):

- **Suspect**: The suspect is a 33-year-old Black male, a known burglar, who as an adolescent had a history of fetish-related break-ins and other behavioral disturbances. He was identified as a suspect when a stolen handgun, taken from a nearby house close to the scene of the latest murder, was found in his possession. Pubic hairs discovered at each of the crime scenes were of Negroid origin and determined to match the suspect. The subject, a self-proclaimed admirer of law enforcement, was fascinated by police work. He owned police scanners and told people that he worked for the police and the FBI. He was also obsessed with serial murder cases and was reportedly well-informed about the *Ted Bundy* and *Green River Killer* cases. He closely followed the news, clipping articles and collecting photographs of the victims. He would compare them with each other and mock police investigative techniques. *He often commented that the only way the police would catch the killer was if trace evidence were left behind.*
- **Evidence:**Each of the victims' bodies bore pubic hairs of Negroid origin found on or near them. Seminal fluid recovered from the first victim was matched to the suspect through DNA testing. Police located the vehicle used to transport the first victim and discovered blood on the front seat cushion, which DNA analysis confirmed to belong to the first victim. Investigators also found a witness who identified one of the rings stolen from the second victim; the suspect had attempted to sell the ring to this witness. A ring stolen from the last victim ultimately led investigators to the suspect.
- **Signature Aspect:** Each murder was sexually motivated. Every victim was discovered completely nude, with the bodies positioned face-up to display the breasts and genital area. The victims had been arranged and/or posed after death with props and/or objects inserted into or placed upon their bod-

ies. It was evident that the killer spent a considerable amount of time with each victim and engaged in activities that went beyond what was necessary to cause death. There was a clear progression in the level of violence inflicted upon each successive victim. The cause of death in every case was blunt force trauma. From each victim, the offender took trophies - such as clothing, rings, and jewelry. Every crime scene revealed pubic hairs of Black origin, indicating an African American perpetrator.

An exceptionally suggestive portrayal of a *contract killer's signature pattern* is presented in the acclaimed Turkish TV series *Yargı (2021)*, where the character of the murderer is shaped through a dark fusion of family trauma and learned violence. After his mother died during childbirth, he was raised by his father, a butcher, from whom he learned the technique of animal slaughter at an early age. According to his own testimony, he developed a *perverse sense of pleasure* while watching blood. His first murder was both *personal and symbolic* - he executed his own uncle on his father's orders - thus beginning a path of no return. Over time, he turned killing into a profession completely devoid of empathy, combining cold rationality with a *ritualistic pattern of behavior* that constitutes his unique *signature*. In practice, together with an accomplice, he would *abduct his victims* and take them to a secure hideout, where he offered them the *illusion of choice* - asking them to decide for themselves how they wished to die - and then fulfilling their "wish" with eerie composure. Yet, his act did not end with the killing itself. In the final stage of the ritual, guided by *deeply rooted yet perverted religious symbolism*, he would prepare the bodies for "burial" according to Islamic custom: performing the ritual washing *(Ghusl)*, wrapping them in cloth *(Kafan),* and finally *returning them to the victims' own homes*. In this way, the crime acquired a dimension of *grotesque* "spiritual symmetry" revealing the psychological complexity and *perverse need for control* that lies at the very core of *his signature behavior.*

Why is the offender's signature not always present in every crime?

The crime scene often serves as a key source of information regarding the unique *signature* elements of the offender, particularly through traces that indicate excessive or unnecessary use of force. For instance, an abundance of blood scattered across various surfaces within the area where the crime occurred may suggest that the victim was moved, dragged, or subjected to prolonged violence. Such evidence points to the application of force that exceeds what is functionally necessary to subdue the victim - whether in the context of sexual violence or the act of murder itself. Such actions are not merely part of the technical execution of the crime. They often reveal strong internal emotions and tension within the offender. Through them, it becomes evident how the offender experiences control, power, or gratification from inflicting violence - emotions that go beyond the functional purpose of committing the crime.

Variations in profiling practices have led to inconsistencies regarding the reliance on evidence, the conclusions drawn, and the investigative usefulness of profiles (Almond et al., 2011; Fox et al., 2020). *The offender's signature* is not always present in every crime committed by a serial offender. Unforeseen events - such as interruptions or unexpected reactions from the victim - may compel the perpetrator to abandon certain unnecessary steps. In such instances, the offender often feels unsatisfied or unfulfilled by the act. Why does this happen? Violent crimes often originate as fantasies within the offender's mind, particularly among serial offenders. As they fantasize and dwell on their thoughts, they develop an increasing need to act out these violent fantasies. When they finally do, certain aspects of the crime reflect their unique personal expression of these fantasies - a process referred to as *personalization*. When the offender repeats their crimes, this personalization recurs and becomes their *signature*. The elements that constitute the *signature* represent the most specific manifestations of the offender's fantasies and are therefore the most meaningful to them (Douglas and Douglas, 2006). Another reason for the absence of *signature* elements in some serial crimes is that investigators do not always have access to surviving victims or the original crime scene. Violent crimes often involve high-risk victims, which may mean that no one reports their disappearance, and consequently, no search is conducted for them or their remains. Many offenders dispose of bodies far from the crime scene, often in isolated locations. This can lead to significant decomposition, making it difficult to detect traces of the *signature* on the body or clothing of the victim. If the body has been discarded, the true crime scene - and most indicators of the offender's *signature* - are located elsewhere (Douglas and Douglas, 2006). Such practices of body disposal not only serve as attempts to conceal evidence but also reflect the offender's continued sense of control over the act and its outcome -a psychological extension of the offender's need to maintain power even after the crime has been completed.

Although identifying an offender's *signature or personal mark* is often complex and demanding, it can represent a crucial element in the process of identifying a serial criminal. Unfortunately, the harsh reality is that the more victims there are, the more evidence emerges that may reveal a recognizable *signature* of the perpetrator. These traces enable investigators to link crimes together and ultimately identify the individual responsible. Investigators work tirelessly to stop violent serial offenders, yet the process often requires comprehensive evidence collection. This includes analyzing evidence obtained from multiple victims, examining crime scenes and body disposal sites, reviewing witness statements, and consulting other sources of information (Bjelajac, 2025: 285). Such findings allow for the identification of characteristic *signature* elements that connect multiple crimes committed by the same serial offender, providing crucial insights into their operational patterns and underlying motivations.

A concise overview of practical examples of activities displaying a signature pattern

It should be noted that the possible examples of *signature*-related activities are virtually countless, as they are based on the offender's fantasies, which can encompass almost anything. However, Gebert has provided several examples drawn from cases in which he was involved as a homicide investigation consultant (Gebert, 2003: 726–728; Gebert, 2006: 831–833):

- **Offender:** tears or rips clothing from the victim's body; forces the victim to remove their clothing; uses the victim's underwear for binding; exerts *complete control* over the victim; binds the victim in an explicit manner, e.g., binding hands and feet behind the back, using sliding knots, a noose, or a ligature around the neck; uses a specific type of binding material, e.g., rope, adhesive tape, duct tape, parachute cord, twine, wire, electrical cable, nautical rope. This may also indicate the offender's particular interest. Places a blindfold over the victim's eyes and mouth; rapes the victim while their hands are bound behind their back; binds the victim while they are naked; engages in postmortem binding; commits sexual assault while the victim is bound; follows a specific sequence of sexual acts with the victim, e.g., anal intercourse, then forced fellatio, then rape; dresses the victim in clothing or underwear brought to the crime scene that does not belong to the victim; brings sexual toys or instruments for use on the victim; masturbates on the victim's body; brings petroleum jelly for use during the sexual assault; positions the body in a specific posture, e.g., naked, with legs splayed, buttocks raised, face down, face up, in a sleeping position, covered, or redressed; targets a specific victim type; engages in mutilation and torture before the victim's death; performs mutilation after the victim's death; engages in necrophilia; practices anthropophagy (consumption of blood and/or flesh); removes body parts, e.g., breasts, nipples, vulva, penis, buttocks, hands, feet, head, scalp.

Gebert, through several other examples based on cases in which he was involved as a homicide investigation consultant, continues as follows (Gebert, 2003: 726–728; Gebert, 2006: 831–833):

- **Offender:** exposes parts of the victim's body to provoke shock; places parts of the victim's body into the victim's mouth or body cavities, e.g., places a severed breast into the victim's mouth or inserts a severed penis into the throat of a decapitated victim; positions the body against an object at the crime scene or against something he brought. Any staging, supporting of the body with objects, or insertion of items into body orifices or other body parts is considered a *signature*; repeatedly stabs the victim in sexual regions, such as the breasts, buttocks, chest, or genitals, which is considered excessive wounding; uses a specific method to kill his victims (strangulation, blunt-force trauma, stabbing, shooting, drowning, electroshock, burying a live victim, etc.); targets a female victim with a child present; because of the child, the victim is inclined to cooperate with his demands; sneaks into the victim's bed while she is sleeping, surprises and attacks her in bed; manually strangles his victim; uses a ligature in strangulation, e.g., rope, clothing, or something he brought to the crime scene; shoots his victims in specific locations, e.g., the head, chest; uses a particular type of weapon; employs a blunt instrument to strike the head or brutally beats his victims; engages in bondage play, and when the victim is helpless and vulnerable, the offender escalates to physical torture.

The offender often uses previously recorded video or audio footage of past victims as a means of psychological intimidation, showing them to the current victim in order to emphasize the power and control he possesses. In certain cases, the victim is held captive - as a sexual slave or hostage - in a strictly confined space such as a cage or an enclosed box resembling a coffin, through which the offender further asserts dominance and complete dehumanization of the victim.

Figure 3*. The notorious American serial killer Ted Bundy, who had twisted motives* and brutal methods, *confessed to killing 30 women across 7 states in the mid-1970s (Delmonico, 2019).*

Ritual and *signature* are fantasy-driven, repetitive behaviors at the crime scene that have been identified as characteristic of serial sexual homicides (Schlesinger et al., 2010). A sexual fantasy is, by its nature, a mental construct that does not necessarily have to manifest in reality. However, in individuals prone to violence or deviant behavior, attempts to translate such fantasies into the real world often lead to the development of a distinct *signature*. The more the offender strives to bring elements of his fantasy to life, the more recognizable and consistent his actions become during the commission of the crime. For example, serial killer Ted Bundy often committed his crimes according to a repetitive pattern that reflected his inner fantasies. His *signature* involved approaching victims with a false display of vulnerability, often pretending to be injured in order to attract their attention and assistance (Bjelajac, 2025: 289–290). This behavioral pattern, although not essential to the act of killing itself, represented an expression of his obsessive need to maintain complete control over the victim and the situation - stemming from deeply ingrained fantasies of dominance, power, and the subjugation of others.

Discussion: The Representation of Signature Behavior in Contemporary Crime Series

Within the conducted research, representations of *signature* behavior in contemporary crime series were analyzed (Bjelajac, Filipović, 2022a; Bjelajac, Filipović, 2022b), with special emphasis placed on the psychological and forensic dimensions of this concept. Unlike the *modus operandi*, which reflects the technical aspects of committing a crime, the *signature* in these series functions as a symbolic expression of the perpetrator's inner need, most often manifested through ritualistic, emotional, or artistically shaped behavior. A more extensive analysis included the series *Criminal Minds, Dexter, Mindhunter, True Detective, Hannibal,* and *The Following*, which consistently depict various types of *signatures* - from trophies and rituals to artistic representations of crime. In *Hannibal,* for instance, murders are aesthetically composed, turning the *signature* into a work of art, while in *Dexter*, the main character creates a personal archive of blood samples from his victims. In *True Detective*, the *signature* takes on a symbolic form - ritual figures and crowns made of antlers - which point to religious and metaphysical motives behind the crime. Such portrayals contribute to the popularization of the *signature* concept but often simultaneously simplify its interpretation, transforming psychologically complex phenomena into visual metaphors. Despite this, these series offer significant potential for analytical comparison with real-life cases, as they illuminate key differences between the technical and emotional aspects of crime.

Contemporary crime television series offer a unique opportunity to explore the inner psychological world of the offender, focusing on their *signature* as a reflection of personal fantasies and emotional needs. In *Mindhunter*, interactions between FBI agents and suspects, along with analyses of their rituals, demonstrate how the repetition of certain patterns - including victim selection, specific body positioning, and manipulation of the crime scene - represents a form of mental preparation that precedes the actual act. Such portrayals illuminate not only the offender's motivations and impulses for control but also clearly differentiate the technical aspects of committing the crime *(modus operandi)* from the elements that serve personal gratification and inner expression *(signature)*. In this way, these series function as narrative and visual experiments, allowing viewers, researchers, and criminology students to identify patterns that might go unnoticed in real cases and to connect outward behavior with the offender's psychological processes.

minate the interplay between fantasy, compulsion, and behavioral expression in serial criminality.

Series	Type of Signature Behavior	Psychological Motive	Forensic Function	Note
Dexter	Collecting victims' blood samples and ritualistically displaying evidence of their crimes	Need for control and re-experiencing the act of murder as a way of channeling inner conflict	Trophy element representing a stable indicator; can be used to identify behavioral patterns and connect crimes	The signature reflects a ritualized act of self-affirmation and a symbolic compensation for moral ambivalence
Hannibal	Aestheticization of murders and symbolic staging of bodies within an artistic context	Narcissistic fascination with the aesthetics of death and rationalization of aggression through artistic expression	Visual forensic signature through patterns of staged bodies and spatial compositions	The signature manifests as an artistic sublimation of aggressive and destructive impulses into an aesthetically shaped composition
True Detective	Ritual figures, spirals, and antlers placed near the body	Religious symbolism and mythological rationalization of violence	Scene reconstruction through symbolic traces	The signature reflects ritualized symbolism and the ideological framework of violence
Mindhunter	Empirically based analysis of real-life signature patterns of serial killers	Exploration of deep psychodynamic structures and compulsive behavioral patterns	Theoretical and empirical modeling of signature patterns within profiling	The series contributes to the popularization and understanding of the scientific and methodological approach in criminal profiling
The Following	Ideologically motivated reproduction of crimes following the teachings and authority of a cult leader	Formation of a shared identity through ideological and emotional identification with the leader	Collective signature pattern manifested through group ritual behavior	The signature functions as a means of ideological control, collective manipulation, and legitimization of violence
Criminal Minds	Ritualized behavioral patterns expressed through messages, symbolic artifacts, and trophies	Fulfillment of fantasies and psychological compensation through a narcissistic need for recognition	Standardized forensic-psychological model of FBI analysis of signature behavior and its variations	The series depicts the classic dynamic relationship between signature behavior and modus operandi in forensic profiling

Figure 4. *Comparative Analysis of Signature Behavior in Crime Series*

Series such as *The Following* and *Criminal Minds* further illustrate how *signature* elements can mediate between the artistic interpretation of a crime and actual criminal behavior. The ritualistic behaviors and repeated symbolic gestures are not only visually striking but also serve as a means to explore the dynamics of power, control, and obsessive impulses. The depiction of trophies, objects, and meticulously constructed scenes emphasizes the offender's obsessive dedication to their fantasies and their material realization. Through these narratives, viewers gain insight into how serial killers internalize their fantasies and project them into reality through consistent and recognizable patterns. Through this narrative approach, the series do more than simply present the *signature* as a plot device - they guide the viewer into the offender's mindset and reveal the psychological motives that drive their actions.

The table below presents a comparative analysis of *signature* behaviors in selected crime television series. This analysis is based on an interpretative rather than empirical approach, offering an original synthesis of forensic and psychological concepts as depicted through the lens of popular culture. It highlights recurring motifs, ritualistic patterns, and symbolic gestures, demonstrating how fictionalized narratives can mirror underlying psychological processes observed in real-world offenders. By examining these portrayals, the study provides a framework for understanding how media representations can illu

The results show that *signature* behavior is present in about 40% of the analyzed episodes, where it is portrayed as a stable psychological indicator that helps investigators identify the motives and profiles of offenders. In approximately 30% of cases, the *signature* appears in the form of ritual elements, while in 10% of cases it is represented as a trophy or an object of sentimental value to the perpetrator. Around 20% of portrayals of *signature* behavior in the series have a symbolic or artistic dimension, confirming that popular culture often uses the *signature* as an aesthetic tool, whereas forensic reality emphasizes its stability and connection to inner impulses and fantasies. Compared to real criminal cases, the series faithfully reflect the basic principles of the *signature* but often exaggerate its frequency and significance in every investigation. Nevertheless, as an educational model, they contribute to the understanding of behavioral patterns and to the popularization of profiling as an interdisciplinary method in forensic psychology.

Concluding Considerations

Criminal profiling seeks to identify key personality traits and behavioral patterns of an offender based on how the crime was carried out. This field has evolved gradually, undergoing several stages of refinement since psychologists and psychiatrists first began applying it in modern investigative practice (Petherick and Brooks, 2020). The analysis of the *signature* in criminal profiling confirms that this phenomenon represents one of the most stable and reliable indicators of an offender's inner psychological structure. Unlike the *modus operandi*, which adapts to circumstances and experience, the *signature* remains a consistent expression of the emotional and symbolic needs that motivate the crime. It reveals the dynamics of fantasies, rituals, and impulses that go beyond the mere purpose of the act, thereby offering deeper insight into the offender's motives and identity.

The research results indicate that the *signature* is not universally present in every crime but depends on a number of factors - such as emotional stability, situational circumstances, and the conscious attempt to conceal traces. When a *signature* can be clearly identified, it becomes a valuable investigative clue: it allows investigators to link cases that may seem unrelated at first glance, trace how the violence develops over time, and build a clearer psychological picture of the offender.

The practical and research application of the *signature* concept demonstrates that its recognition is of crucial importance in the investigation of serial crimes. The analysis of real cases and their portrayals in contemporary crime series confirms its multilayered role - from a diagnostic tool in forensic psychology to a methodological instrument for interpreting offender behavior. Although popular culture tends to simplify its interpretation, it has contributed to the affirmation of this topic and to its broader understanding within both the public and academic spheres.

In conclusion, the *signature* can be viewed as the offender's emotional-psychological code - a stable, recurring, and symbolic pattern that links the perpetrator's inner world with the external act of crime. Its analysis not only contributes to more precise profiling and more efficient resolution of serial crimes but also opens new fields of research into the psychodynamics of criminal behavior. This study confirms that the analysis of the *signature* must become an integral part of contemporary criminological and forensic methodologies, as it enables a deeper understanding of the motivation, identity, and behavioral continuity of offenders.

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Conflict of Interest

The author declares that there is 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 in full compliance with applicable research ethics standards.

Author Contributions

Personal contribution. The author has read and agreed to the published version of the manuscript.

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Hirsch, Jr., E. D. (1996). *The schools we need and why we do not have them*. New York: Doubleday.

• When you mention a paper published in a journal or as part of a book as a chapter, then applies the following form:

The author's name [comma], initial / names [point], [open small brackets] year of publication [close little brackets] [point] title of the paper [point], In Proceedings ... (note that the work was published in a journal or book ...) The name of the publisher [open small brackets] Issue. (Note that this is a publisher) [Close little brackets] [comma] title of the collection - in italics [open small brackets] page starting work [line] Page completing work [point], the city (and state) [two counts], publisher [point].

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.

• If seven or more authors, then we will list the names of the six authors, and the seventh and the rest fall into the category of '' and associates ''.

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.

Second and last author in a list of references are always stating afterward conjunctions & English.

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the author's name [comma], initial / names [point], [open small brackets] day, month and year of publication [close little brackets] and the title [point], the name of the magazine or newspaper - italics [comma], number of journals or Newspapers - italics [comma], page beginning of the text [line] Page completing the text [point].

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 cholinoceptive 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 Troscott & 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).

• When you cite articles published on the university or one of the official institutions, universities, publishers listed as the first name of the university and then university.

Broadhurst, RG, & Maller, RA (1991). Sex offending and recidivism (Tech. Rep. No. 3). Nedlands: University of Western Australia, Crime Research Center.

• When the list of sources cites a report of an organization or institution that has no author, it is best to nominate as the author of this organization, which is also the publisher.

Employee Benefit Research Institute. (1992, February). Sources of health insurance and characteristics of the uninsured (Issue Brief No. 123). Washington, DC: Author.

• When the work was published on the Internet as a photocopy, it should cite the original source noting that this is the electronic version.
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.

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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

• When you download from the Internet a document which has no date or author, then the document name takes the place of the author or the first place.
8th GVU's WWW User Survey. (Od). Retrieved August 8, 2000, from http://www.cc.gatech.edu/gvu/user_surveys/survey-1997-10/

• Material from the symposium or a scientific paper which was only exposed, but not published, listed with the note on which the scientific or professional meeting is material exposed. If the author has presented on the site, it is desirable to name and web page.

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 Sesvice.

• 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

Standards take according to Suzic, N. (2010). *Pravila pisanja naučnog rada APA i drugi standardi* [Rules scientific APA work and other standards]. XBS Banja Luka.

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Reference Manager (http://refman.com/support/rmstyles.asp).
Above management software have plug-ins to word processing where authors only need to select the appropriate journal template when preparing their article and the list of references and citations to these will be formatted according to the journal style as described in this Guide. If you cannot find an available template, see the list of sample references and citations provided in this Guide to help you format these according to the journal style.

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