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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 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.

All articles are published in English and undergo a peer-review process.

The scope of IJCRSEE is focused on cognitive research both in topics covered as well as disciplinary perspective:

- Cognitive Research in Education
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- Cognitive Psychology
- Forensic Psychology
- Psycholinguistics
- Cognitive Linguistics
- Cognitive Culture Studies
- Cognitive Neurophysiology
- Cognitive Aspects: Sport Culture
- Cognitive Aspects: Methodology of Knowledge
- Text Processing and Cognitive Technologies

- Curriculum Development
- Development of Learning Environment
- Education Administration
- Educational Psychology
- Educational Technology
- Elementary Education
- Innovative Pedagogical Models
- Learning Systems Platforms
- Media Education
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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.

The names and email addresses entered in this journal site will be used exclusively for the stated purposes of this journal and will not be made available for any other purpose or to any other party.

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 18 articles (16 Original researches and 2 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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Improving the Cognitive Flexibility (CF) of Adolescent Students Through Differentiated Instructions in Indonesia

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Abstract: Students are expected to be adequately prepared to respond to technological advancements and complex global challenges. In this context, cognitive flexibility plays a crucial role in facilitating the development of appropriate alternative strategies. Previous research has identified several relevant learning activities aimed at enhancing cognitive flexibility. In the context of differentiated instruction, cognitive flexibility is further elaborated through consideration of the individual uniqueness of students, the learning situation, and the environment, making this concept particularly relevant to the educational setting in Indonesia. Consequently, this study aimed to enhance the cognitive flexibility of adolescent students through differentiated instruction training. A total of 70 adolescent students participated in a one-group pretest-posttest experimental design using convenience sampling. The participants completed an informed consent form and engaged in training activities for approximately 4 weeks. The findings indicated that 66% of participants showed an increase in cognitive flexibility attitudes following the learning intervention. Furthermore, inferential statistical analysis revealed significant differences between pretest and posttest results. The differentiated instruction training proved effective in improving cognitive flexibility attitudes. This research has implications for the development of effective learning models and provides recommendations for the enhancement of skills among adolescent students, not only within the context of Indonesia but also for potential implementation in different cultures and locations.

Keywords: *adolescent, cognitive flexibility, differentiated instruction, students' diversity.*

Introduction

The complexity of learning is subjecting individuals to increasingly challenging conditions. In this context, the rapid advancement of technology with diverse global demands has intensified the complexity of learning (Amir et al., 2020; Dargan et al., 2020; Oke and Fernandes, 2020). Even though learning was conducted through a face-to-face classroom system, the concept has evolved into an open and distance model. The presence of teachers has innovated through the many sources of contemporary and limitless learning. The changes should be anticipated adaptively, solution-oriented, and sustainable to obtain optimal learning outcomes. Therefore, a strong positive character and skills relevant to the various complexities must be shown (Ramdani et al., 2024; Zuhdiyah et al., 2024). One of them is cognitive flexibility skills which are important for individuals to deal with various situations.

Cognitive flexibility increases the ability to adapt to existing complexities (Leimar et al., 2024). This also improves performance in tasks that require adaptation to new rules or conditions (Tello-Ramos et al., 2019). Recent research explained that cognitive flexibility was an important characteristic, specifically for

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students in carrying out the learning process (Ionescu, 2012; Richard's et al., 2021). Cognitive flexibility plays a role in directing, establishing, and providing problem-solving strategies (Braem and Egner, 2018). The variable describes the behavior of an individual and is directly related to the level of intelligence (Ionescu, 2012). However, it can be trained, developed, and optimized through a series of activities connected to learning principles (Braem and Egner, 2018).

In several scientific research, cognitive flexibility was analyzed from various perspectives. From a psychological perspective, cognitive flexibility is a positive character obtained from a continuous learning process accompanied by reinforcement from the environment an individual grows and develops (Dennis and Vander Wal, 2010; Ionescu, 2012). Cognitive flexibility is based on basic associative learning mechanisms conditioned by simple incentives and influenced by bottom-up contextual cues, including subliminal cues (Braem and Egner, 2018). From a medical and neuroscience perspective, cognitive flexibility is acquired due to genetic results, innate intelligence, and optimal function in the brain (Dajani and Uddin, 2015; Kehagia et al., 2010; Masley et al., 2009). Additionally, it is supported by a distributed network through the integration of the frontal, temporal, and parietal lobes in the brain (Dajani et al., 2020; Uddin, 2021).

Cognitive flexibility is seen as an important skill for individuals to survive in the complexities of life to achieve optimal learning (Dajani and Uddin, 2015; Ionescu, 2012). Several researchers have tried to find strategies used to improve the concept. From a health perspective, cognitive flexibility can be improved through aerobic activity (Masley et al., 2009), fitness, and monitoring (Themanson et al., 2008), as well as dancing activities (Coubard, 2011). This has been shown to support daily life functions such as reducing symptoms of depression and eating disorders (Duriez et al., 2021). In social science, specifically education, many learning methods can be used to improve skills, such as metacognitive training (Buttelmann and Karbach, 2017), reasoning training (Scheibling-Sève et al., 2022), as well as technology-based learning activity and innovation (Wang and Jou, 2023). This research has succeeded in increasing the cognitive flexibility of participants in the implementation.

Intervention through training programs can significantly increase individual cognitive flexibility. The training has a direct effect since the goals to be achieved must be specific (Van Bers et al., 2020). In addition, the development can vary across different cultural contexts. Hence, curriculum design needs to consider individual experiences (Legare et al., 2018). In the Indonesian context, cognitive flexibility is very important because curriculum changes are often a major problem facing the world of education. These changes require many aspects, starting from the readiness of schools, teachers, and students (Ramdani., 2022; Wigati et al., 2023). Increased accessibility and more visionary educational reform goals compel students in Indonesia to strive harder to acquire these skills (Warsihna et al., 2023). In addition, the diverse demographic differences in the regions, characteristics of the learning environment, and unequal resources are additional predictors of the importance of strengthening cognitive flexibility (Ramdani et al., 2021).

Cultural variations have been reported through the diversity of individual executive function development. In the US, rule-switching flexibility shows an increase in early childhood, in contrast to children in South Africa. Rule-switching flexibility depends on certain types of cultural experiences, while word-learning flexibility, is less culturally varied (Legare et al., 2018). Research on cognitive flexibility is often associated with problem-focused coping and the role of other learning variables (Aprianto et al., 2021; Oktaviani et al., 2021). Experimental research including cognitive flexibility was conducted Aprianto et al. (2021), but the procedures carried out were not clearly described. Therefore, a clear picture of the right learning model has not been provided for improving cognitive flexibility.

The diversity in various aspects of education, coupled with the current independent curriculum policy opens up opportunities to learn with a differentiated instruction model. In this context, differentiated instruction emphasizes the excellence and diversity of students as the main benchmark in providing learning relevant to the conditions (Kahmann et al., 2022; Sharp et al., 2020). Theoretically, this principle further strengthens the function of cognitive flexibility. Teachers can provide a variety of activities requiring students to learn actively and adaptively. Students can also be trained by using the abundant environmental resources. Therefore, there is a rationale for considering differentiated instruction as a learning strategy in line with independent curriculum policy and cognitive functions in students.

Differentiated instruction is a relevant learning model to be applied in improving cognitive flexibility. Based on research on human cognitive architecture, cognitive flexibility is related to the interaction of information stored in memory (Eriksson et al., 2015; Sylvia, 2019). Teachers can design learning activities

related to the diversity of children such as interests and talents, learning styles, as well as experiences (Ramdani et al., 2022), including background knowledge. The initial conditions of learning are information schemes that have been formed in long-term memory and should be repeated during the learning process to increase the complexity of existing information (Hartshorne and Makovski, 2019). This process will influence learning and self-efficacy, leading to improvement (Wang and Jou, 2023).

The differentiated learning model is fairly complex because the concept includes a specific part of the individual and the resources possessed. Several activities carried out in differentiated learning have a direct role in training responsiveness to be ready to face existing academic problems (Variacion et al., 2021). Students will be taught skills in conducting self-evaluation, self-reflection, and using limited resources more optimally (Griful-Freixenet et al., 2020; Seddon et al., 2021; Variacion et al., 2021). Therefore, activities in differentiated learning strive to strengthen cognitive flexibility (Griful-Freixenet et al., 2020, 2020; Seddon et al., 2021; Variacion et al., 2021).

According to Veraksa et al. (2020), differentiated instruction given to elementary school students through identical activities can improve cognitive functions. Another research reported that cognitive abilities were improved through differentiated instruction by considering readiness and adjustment to different contexts, situations, and individuals (Stollman et al., 2019). In Indonesia, there has been no research that directly identifies the effectiveness of providing differentiated instruction. In developing cognitive flexibility, students of school age or categorized as adolescents tend to learn faster than adults, with changes in processing in the anterior insula of individuals (Hauser et al., 2015). Therefore, this research aimed to determine the effectiveness of differentiated instruction training in improving cognitive flexibility in students. More comprehensive recommendations are provided with an effective program model for improving the cognitive flexibility needed by Indonesian students.

Materials and Methods

Research Design and Ethical Approval

This research uses an experimental method with a one-group pretest-posttest design model (Knapp, 2016). The experimental model is used to measure the intervention given to a group of participants by comparing the values at the beginning and the end of the measurement. The experiment was carried out by measuring the initial conditions of the participants. At a certain time, the participants were given treatment predicted to improve initial conditions to be more optimal. After the intervention was given, measurement was carried out using the same instrument to determine the final condition. The significance of the changes will determine the success or failure of the experiment. To minimize bias in measurement, the researchers ensured that the experimental study was conducted objectively in terms of manipulation, observation, and control. Additionally, this study was overseen by an ethics committee responsible for ensuring that the activities were conducted in accordance with established research ethics. This research has received approval and passed the feasibility test by the Social Sciences and Humanities Ethics Commission of the National Research and Innovation Agency (BRIN) of Indonesia with number 173/K3.01/SK/04/2023.

Participants

The research populations were students at one of the Junior high schools in Bandung City. These individuals are at the adolescent development level where the optimization of cognitive function becomes very important, specifically in supporting the opportunity for academic success (Herting and Chu, 2017; Steinberg, 2005). The number of participants in the population was 500 (180 students in grade VII, 170 in grade VIII, and 150 in grade XI). In addition, participant willingness sheets were distributed to obtain students willing to be part of the research. The researchers provided an informed consent form that clearly outlines the agreement between the researchers and participants. This includes the benefits that participants may gain, the limitations of the study, as well as the freedom to withdraw from the study at any time as per the agreed terms. Since the participants are still in their adolescent years, we also ensured that permission was obtained from the school, teachers, and parents involved.

The selection method used a convenience sampling system to obtain suitable samples (Bhardwaj, 2019; Etikan, 2016). In this study, the sample consisted of individuals who voluntarily agreed to participate

in the research. This study employed a one-group approach because the researchers aimed to provide a comprehensive intervention to all participants, and therefore, no participants were assigned to a control group. However, the researchers will still selectively filter the data based on the completeness of the information provided by the participants.

Measurement Instrument

The Cognitive Flexibility Inventory developed by Dennis and Vander Wal (2010) was used to measure cognitive flexibility in participants. This instrument measures the attitude in facing challenges and changing maladaptive thoughts for the better. The instrument consists of 20 items that measure 3 dimensions of individual cognitive flexibility, namely, the tendency to embrace difficult situations, the ability to accept alternative explanations, and the ability to apply alternative solutions. There are 7 alternative answers provided in the instrument ranging from 1-7. A score of 1 shows that the individual strongly disagrees with the statements and conditions given in the instrument. Meanwhile, a score of 7 indicates a strong agreement with the statements.

The instrument used was first adapted into Indonesian in adjusting to the language and culture of the participants. This adaptation process refers to the guidelines explained by Beaton et al. (2000), namely translation, synthesis, back translation, expert committee review, and pretesting. The research comprised two expert translators who had more than 2 years of cultural experience abroad and six experts conducting the final review of the adaptation instrument. The final instrument was first tested on 1375 adolescent students, producing a reliability coefficient of .797 and showing a fit model in the validity test with confirmatory analysis.

Experimental Procedure

The experimental activities were carried out through the preparation, implementation, and evaluation phases. The preparation phase starts with selecting a trainer, namely a teacher who has a background in science expertise at each class level. These characteristics were selected based on several previous research where the implementation of differentiated instruction is effective in science subjects (Mathematics, Biology, Physics, and Chemistry). This is because the learning practices are operational and integrate natural resources around the school environment (Sharp et al., 2020; Tomlinson and Jarvis, 2009). After getting a teacher as a trainer, the research team provided training and reinforcement regarding the urgency and use of the differentiated instruction guidebook. At the end of the phase, the trainer made a plan and schedule for implementing the experiment and identified factors affecting the final results. For further details, please see Figure 1, which shows the experimental scheme.

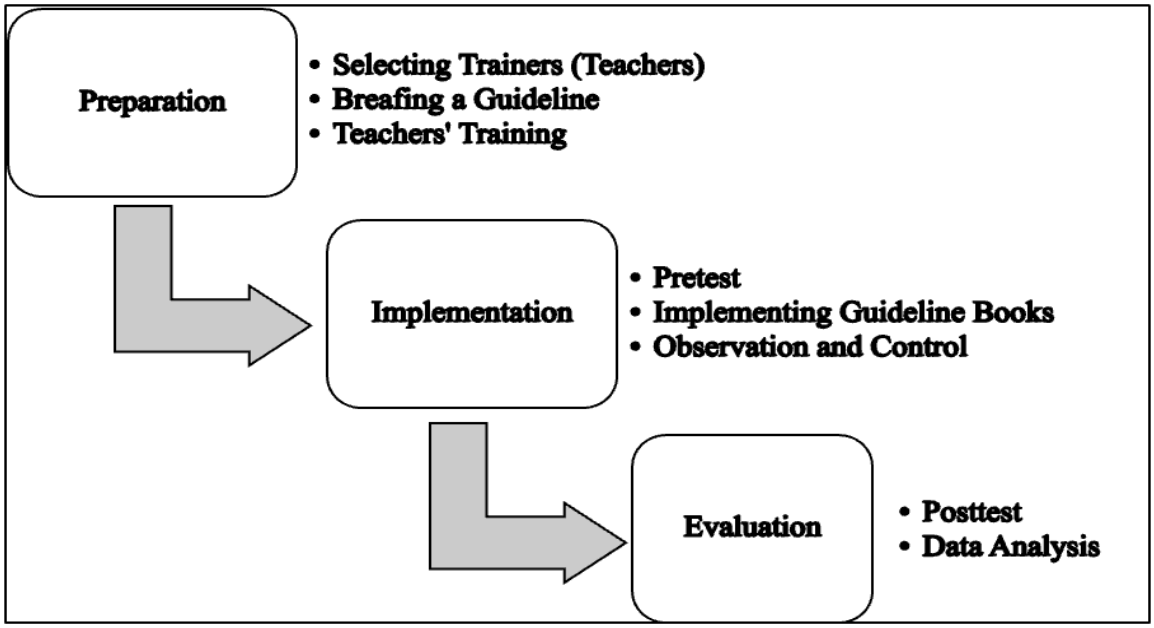


Figure 1. Experimental Scheme

The implementation phase begins by carrying out activities based on the differentiated instruction guidebook. This experimental research was conducted using a validated guidebook. The guide has been provided in soft file form, and the manuscript is published in international proceedings (Ramdani et al., 2022). This instruction guidebook contains general concepts, implementations, and learning practices based on the principle of differentiated learning. The guidebook consists of 7 parts covering the general concept of instruction, learning planning strategies, design, implementation, determining time, identifying learning complexity, and integrating diversity. In each part, there is a worksheet used by teachers to evaluate the learning process. Detailed information for each section will be explained in Table 1 below.

Table 1. *Summary of Differentiated Learning Guidebook Activities*

No	Book Section	Activity	Time
1	General Concept of Instruction	Introduction of concepts and their integration with subject matter	Week 1
2	Learning Planning Strategies	Identifying the learning strategies to be used	Week 1
3	Learning Design	Design in detail every activity that will be carried out	Week 1
4	Determining Time	Make a detailed schedule	Week 1
5	Learning Implementation	Implementation of learning in class with elaboration of material and student conditions	Week 2-4
6	Learning Complexity	Identification of difficulties and relevance of classroom atmosphere	Week 2-4
7	Integrating Diversity	Integration of student needs with learning targets and designs	Week 2-4

Note. The time information given in this book may be adjusted to the field conditions found by the teacher during the experimental process.

The differentiated instruction guidebook has been tested through 2 stages (Ramdani et al., 2022). The first stage was evaluated by experts consisting of lecturers, education practitioners, and external supervisors to obtain input in terms of theoretical framework and implementation. Meanwhile, the second stage of testing was carried out on teachers in 4 different schools as a strategy to determine the readability and usability of the book in learning. The results of the second stage of testing improved the quality of the guidebook to be more practical and on target (Ramdani et al., 2022).

This experimental activity was performed in 3 different classes at the same level (VII, VIII, and IX). The formation has also been agreed on with the school without interfering with normal learning. In addition, the experimental activity was carried out in the first month of the new semester of learning since the school was in the initial administration process. This experiment was performed for 4 weeks, with 2 days each week used by the trainer to implement the guidebook. Implementation was carried out with the learning materials provided by the trainer in class. The trainer was asked to make documentation in the form of photos, activity reports, and general notes on attitudes and behavior during the intervention. This is useful in helping and strengthening the analysis and interpretation process (Baroroh et al., 2024; Rafida and Astuti, 2024). In the final phase, the research collects the results of filling out the questionnaire at the pretest and posttest stages. Additionally, the trainer evaluated the experimental process, and the raw data obtained was prepared for analysis according to the research objectives.

Data Analysis and Interpretation

The data obtained will be analyzed descriptively and inferentially. Descriptive analysis is used to describe the percentage of participant achievement in filling out the questionnaire. Meanwhile, inferential analysis is used to determine the effectiveness of the intervention given to the experimental group. To facilitate the analysis of descriptive and inferential data, the research used SPSS 27 software. Additionally, Rasch Model analysis was conducted using Winstep 3.65 software to ensure unbiased data and identify changes in participant performance. Changes in individual student attitudes were determined by

comparing the pretest and posttest logit (measure) values using the Stacking Rasch Model (Bond and Fox, 2015). The intervention can improve psychological variables in participants when the analysis results are significant (P < .05).

Results

Participant Demographics

A total of 120 students filled out the consent form provided and only 70 filled in the data completely. Demographic data from the 70 participants are presented in Table 2.

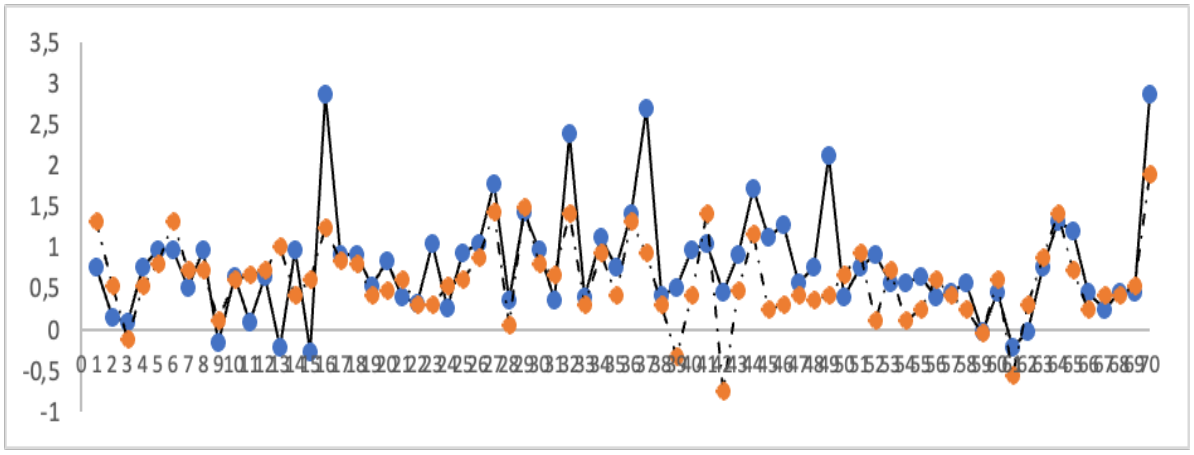
Table 2. *Participant Demographic Data*

Category	Frequency	Percentage (%)
Gender		
Male	35	50
Female	35	50
Age		
12 years	20	28.6
13 years	25	35.7
14 years	21	30
15 years	4	5.7
Class Level		
Class VII	21	30
Class VIII	25	35.7
Class IX	24	34.4

Based on Table 2, the number of male and female participants is the same. From the age data, participants in the 13 and 15-year-old groups reach 35.7% and 5.7%, respectively. The age of the participants ranges from 12 to 15 years old at the adolescent development level (Zhang et al., 2016). Based on the class level, there was no significant difference since the categories were in the range of 30%.

Student Achievement Fluctuation Pretest and Posttest

The raw scores obtained by participants during the pretest and posttest were analyzed using the Rasch Model to obtain the logit value (See Figure 2). In this context, the logit value is a new unit produced by the analysis as the initial answer given in filling out the scale. Therefore, this value can be used as data to be analyzed (Bond and Fox, 2015; Wright, 1977).



Note. Red Line> Pretest Score and Blue Line> Posttest Score

Figure 2. Changes in Participants' Cognitive Flexibility Scores

According to Figure 2, the red and blue lines show the measurements before and after the intervention. Descriptively, there were different changes between one participant and another. However, when viewed, there were 46 participants (66%) who experienced an increase in cognitive flexibility scores during the research process. The results of the score changes were carried out by comparing the size of the pretest and posttest logit (measure) values using the Stacking Rasch Model (Wright, 1977). The analysis showed that the average value of participants in the pretest measurement was 0.601 and 0.798 in the posttest, with a change score of 0.196. A normality analysis was performed to determine the distribution of data before conducting a difference test.

Table 3. *Results of the Data Normality Test*

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest	.096	70	.187	.971	70	.099
Posttest	.152	70	.000	.891	70	.000
Pretest-Posttest	.109	140	.000	.925	140	.000

In Table 3, the normality test is performed to determine the normal distribution of data. A test performed on a single group using Kolmogorov-Smirnov or Shapiro-Wilk analysis shows that only the pretest data is normal. This is indicated by a significance value above the standard (p> .05). Meanwhile, when the analysis is performed on a combined group (Pretest-Posttest), the results are not significant (p<.05). Further analysis should be carried out using the Wilcoxon Signed Ranks Test to determine the significance of changes in abnormal data.

Table 4. *Results of the Pretest and Posttest Difference Test*

	N	Mean Rank	Sum of Ranks	Z	Sig.
Negative Ranks	24	31.73	761.50	-2.815	.005
Positive Ranks	46	37.47	1723.50		
Total	70				

Note. Asymp Sig. (2-tailed)

Based on the information in Table 4, the number of participants who experienced an increase and decrease in score was 46 and 24 individuals, respectively. The significance results showed a score of .005 (p < .05) (Hair et al., 2019). From these results, there was a significant change from the pretest to the posttest score. Interpretatively, these results show that intervention in the form of discovery learning can increase cognitive flexibility in adolescent students in this research.

Discussions

This research was conducted by implementing a learning program based on a guidebook created in previous research. In general, a guidebook aims to provide the most practical information possible from a learning concept into a more operational activity for users. The differentiated instruction guidebook was able to contribute significantly to increasing the cognitive flexibility of adolescent students. This certainly shows the relevance between the intervention given and the target behavior. Consistency between the form of intervention and the content being measured is an absolute in experimental research (Gopalan et al., 2020; Jiménez-Buedo and Russo, 2021).

An advantage of an experimental design using only one group is allowing participants to obtain the required positive intervention (Chen et al., 2021; Little et al., 2020). In practice, differentiated instruction contains operational steps that help students master a lesson in class by considering abilities and supporting resources. In several activity sessions, the teacher allows students to work on assignments according to the learning type. Students with a visual learning type can create assignments using certain illustrations. The activities are not only humanistic for students but can be a stimulus to activate cognitive functions in learning (Pham, 2011; Veraksa et al., 2020). So that their cognitive flexibility abilities can be further honed.

Based on the results of the comparison between the pretest and posttest, there was an increase in cognitive flexibility scores in students with a percentage of 66%. This number has exceeded the average percentage value statistically. Therefore, the majority of students obtained an increase in cognitive flexibility because of the differentiated instruction given. Several factors that contribute to the increase can be explained in different situations. First, student participation in the experimental activity is based on a needs analysis, hence the students are enthusiastic and possess the willingness to change for the better (Ma, 2020; Sun et al., 2021).

The results of observations made by the teacher as a trainer obtain several inspirations when implementing differentiated instruction in the classroom. In addition to the method used being more comprehensive in capturing diversity, teachers also get a picture of more enthusiastic students. Since the basic principle of differentiated instruction is to use surrounding resources as learning inspiration, the model can also improve creativity, collaboration, and other cognitive functions such as cognitive flexibility, critical thinking, and problem-solving (Ginja and Chen, 2020; Magableh and Abdullah, 2021; Pozas et al., 2023). Therefore, activities carried out in class using differentiated instruction will strengthen the psychological variables.

The success of this research is also largely determined by the skills possessed by the trainers. As teachers and trainers in implementing this experiment, many factors contribute to the success of the experiment. Teachers are the main key in implementing the education curriculum, hence the ability to capture existing policies adjusted to the situation in the classroom is a privilege (Kneen et al., 2023). The differentiated instruction guidebook provided in this experiment is a practical book for translating the current curriculum into actual language and learning activities (Ramdani et al., 2022b). Great teachers are those who can theoretically understand the concept of differentiated instruction and manifest the concept in adaptive classroom learning. Therefore, teachers as trainers also make a total effort to provide intervention to students. The guidebook promotes the implementation of the current education curriculum. Some worksheets and evaluations can be used to measure the learning process carried out to easily assess students.

The improvement results were strengthened by significant inferential analysis ($p > .05$). There was a significant difference between the pretest and posttest results of the participants. In this research, intervention in the form of differentiated instruction can be an effective strategy for increasing cognitive flexibility. Cognitive flexibility can be strengthened through an effective learning process. However, the measurements carried out in this research only included individual attitude factors. These attitude factors are measured through self-report instruments in several psychological statements. In the implementation, the biases affected small aspects of the experiment (Giromini et al., 2022; Van Berkel et al., 2020). For example, only 66% of participants in this research were obtained and others experienced a decrease in the cognitive flexibility index. Factors such as child readiness and the conduciveness of the learning environment were also considered with the potential bias arising from the use of self-report instruments (Ejelöv and Luke, 2020; Plucker and Makel, 2021; Van Berkel et al., 2020).

The results of data normality show that the distribution of data is not normal but statistically valid. The differences in class levels also contribute to the abnormality of the data with filling out self-reports which tend to be subjective. There are 3 different class levels in the experimental group. A different analysis was not conducted because each level has different challenges (Alcantara et al., 2017). Meanwhile, the research time conducted within 1 month is also important in considering the learning process applied comprehensively.

This study makes a significant contribution to the provision of effective interventions within the educational system in Indonesia. However, more universally, this study could be conducted in the context of more heterogeneous cultures and countries, and even with different age groups or participant categories. The theoretical model derived in this study can be applied within the context of local wisdom. This means that when the experiment is to be replicated in different contexts, it is certainly possible, but it should first involve adapting the teaching materials and considering the differences in participant characteristics specific to each country. Many studies have successfully replicated such experiments in various contexts. The success of these replications is undoubtedly influenced by several factors, including the relevance and consistency of the philosophical principles used, the accuracy and rigidity of the methodology, the implementation procedures, and the critical evaluation of successes and failures in previous related studies (Kim, 2019; Plucker and Makel, 2021). Considering these factors, this study has the potential to be applied across cultures.

The development of differentiated instruction interventions to improve cognitive flexibility will not stop with this study alone. Further studies are needed to strengthen both the results and the weaknesses

identified. This study was conducted within the local school context, but it can be expected to serve as an alternative model at the global level for educational policy development. Furthermore, the issue of cognitive flexibility addressed in this study is a critical aspect that has become a concern for the government to improve. Thus, this study could serve as an alternative approach to developing these skills. However, many challenges may arise in the implementation process, such as the need for a deep understanding among teachers in various regions regarding the concepts presented. One of the limitations in Indonesia is the difference in the educational structure across regions, which heavily depends on the availability of qualified human resources. Meanwhile, the considerable cost required for numerous training programs will also be an important consideration in this context. If all aspects of education are willing to collaborate to improve the quality of education, then the program developed based on this study could become the best solution for advancing education in Indonesia.

This research has several limitations that can be used in the future as reference material. The number of participants is high for 1 class (70 students), which is considered to affect the learning climate and student performance. Theoretically, there is an effective limit to the number of students in 1 class to learn (Khan and Ghosh, 2021). Future research should increase the number of classes when used as a control group. Meanwhile, the learning process carried out in 1 month should be improved concerning the administrative process.

Conclusions

In conclusion, this experimental research emphasized the role of differentiated instruction in improving cognitive flexibility in adolescent students in Indonesia. The results provided a clear picture of classroom learning practices and activities carried out by teachers as an effective strategy for improving skills. Cognitive flexibility could be optimized as an important characteristic for adolescent students in this modern era. However, the strategy could be relevant to the current curriculum policy in training cognitive aspects with the existence of a learning model such as differentiated instruction. Even though this research was conducted in the context of Indonesian schools, the existing learning model could be applied on a global basis due to the nature of differentiated instruction. Therefore, this research could be a best practice in implementing effective learning, as well as strengthening the uniqueness of the students.

Data Availability Statement

All data used in this study are accessible on the following open-access platform https://osf.io/uty7d/.

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Conflict of Interest Disclosure

We declare that there is no conflict of interest in the preparation of this manuscript.

Ethics Approval Statement

This study obtained ethical approval from the Social Sciences and Humanities Ethics Committee of the National Research and Innovation Agency under reference number 173/KE.01/SK/04/2023.

Patient Consent Statement

All participants involved in this study consciously and voluntarily participated in the research, as evidenced by the informed consent they completed before the commencement of the study.

Permission to Reproduce Material from Other Sources

The authors declare that all tables and figures presented in this study are entirely the original work created by the researchers themselves.

Clinical Trial Registration

This study does not contain any clinical material requiring specific registration. However, the researchers registered all research processes with the ethics committee of the National Research and Innovation Agency (BRIN) of the Republic of Indonesia, and all data obtained from the study are accessible on the international platform OSF.

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Author Contributions

Conceptualization, Z.R., D.H., and M.F.; methodology, Z.R., D.H., and NS.; software, N.A., A.A., and H.C.; formal analysis, Z.R., and D.H.; writing—original draft preparation, Z.R., D.H., M.F., N.S., and N.A.; writing—review and editing, Z.R., D.H., A.A., and H.C. All authors have read and agreed to the published version of the manuscript.

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Evoked Brain Activity in Food Preference Decisions: Links to Eating Behavior and General Nutritional Knowledge

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Abstract: The article explores the characteristics of evoked brain activity during food preference decisions, emphasizing the role of psychological and neurophysiological mechanisms. The relevance of studying eating behavior as a multifaceted phenomenon is highlighted, with attention to the cognitive, emotional, and physiological factors that influence food preferences. The study involved 40 participants (70% female). Psychological testing included the Dutch Eating Behavior Questionnaire (Russian version by I.G. Malkina-Pykh, 2007), the Thought and Behavior Questionnaire (adapted by A.V. Anikina and T.A. Rebeko, 2009), the Three-Factor Eating Questionnaire (Russian version, 2018), and the General Nutrition Knowledge Questionnaire (translated version of Kliemann, 2016). Neurophysiological data were collected using EEG tasks based on a Go/NoGo paradigm. Mathematical and statistical methods included the Shapiro-Wilk test, Mann-Whitney U test, Student's t-test, and k-means cluster analysis. The study revealed significant differences in brain activity between groups with varying psychological characteristics and levels of nutritional knowledge. These findings align with previous research, confirming the link between cognitive control, impulsivity, and food preferences. Enhanced activation in the temporo-occipital regions was observed in participants with higher nutritional awareness. The role of psychological traits was found to outweigh knowledge levels in shaping dysfunctional eating patterns, highlighting the need for individualized approaches in prevention and treatment. The limitations, including the sample size and absence of participants with clinical eating disorders, are discussed alongside recommendations for future research.

Keywords: *eating behavior, rational consumption, cognitive control, evoked activity, ERP, Food Preference.*

Introduction

In recent years, research on the psychophysiological mechanisms of eating behavior has expanded into several distinct directions. Numerous studies highlight distinctive patterns of brain activity in individuals with eating disorders, with meta-analyses identifying key research areas (Wonderlich et al., 2021). One of these focus areas includes examining cognitive control and reward system mechanisms through neuroscience-derived approaches.

fMRI studies have shown the significance of the reward system in regulating eating behavior. Alterations in the reward system have been observed in individuals with compulsive overeating, characterized by heightened responsiveness to food stimuli. This sensitivity is associated with stereotypical behavioral patterns and increased susceptibility to external food cues (Leenaerts et al., 2022; Vrieze and Leenaerts, 2023). It was also shown that the activation patterns of the reward system in response to food stimuli can predict not only food preferences but also Body Mass Index (BMI) (Cosme and Lopez, 2020). These findings are supported by twin studies, which reveal that childhood impulsivity and reward system activity correlate with BMI in adulthood. This highlights the long-term influence of early reward system functionality on eating behavior (Kan et al., 2020). Variations in reward processing and cognitive control play a significant role in shaping food preferences and obesity risk. Dysfunctions in the orbitofrontal cortex, which integrates food reward signals, have been linked to heightened responsiveness to food cues and overeating (Rolls, 2021).

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Building on the understanding of the reward system's role in eating behavior, cognitive control has also emerged as a critical factor influencing maladaptive weight-loss strategies in eating disorders. Deficits in cognitive control are closely linked to impulsivity, a key predictor of pathological overeating (Пичиков et al., 2018; Oliva et al., 2019). Studies demonstrate that individuals with compulsive overeating exhibit reduced inhibitory control and attentional selectivity, which also impacts cognitive task performance. For instance, differences in brain activity during Go/NoGo tasks have been observed predominantly in individuals with severe disorders manifestations (Berner et al., 2023; Lyu et al., 2018). Moreover, cognitive control levels have been shown to predict treatment outcomes in cognitive-behavioral therapy (CBT) for eating disorders, particularly binge eating and obesity, as well as the durability of remission. For example, individuals struggling with interference control in the Stroop task exhibited lower treatment efficacy (Hamatani et al., 2021).

ERP studies have highlighted distinct neural correlations of eating behavior in individuals with excess weight, particularly the P300, N200, and P200 components. These components reflect variations in cognitive control, behavioral regulation, and appetite response. A systematic review (Chami, 2019) of ERP studies of neural responses to food and non-food stimuli among individuals with eating and weight disorders revealed an enhanced attentional bias toward food stimuli, as evidenced by elevated P300 and LPP amplitudes, across groups of individuals with excess weight from those of healthy weight. However, among individuals with obesity, the N200 amplitude positively correlated with caloric intake, while the P300 amplitude was sensitive to hunger levels (Chami, 2019).

P300 amplitude increase in response to food stimuli, regardless of type, has been observed in groups with excess weight. Interestingly, the presence of this component, coupled with a preference for low-calorie food in experimental settings, also predicted snack frequency within the sample. Similarly, the emergence of the N200 component has been associated with low levels of eating behavior control in obesity (Biehl et al., 2020). The P200 component has also been highlighted in several studies, showing increased prevalence in individuals with excess weight in response to food stimuli (Liu et al., 2020; Schwab et al., 2021). This component has been linked to appetite suppression when a discrepancy arises between expected and actual food stimuli (Schwab et al., 2021). However, the relationship between cognitive control and obesity remains ambiguous, as some animal studies suggest that rather than cognitive control deficits causing obesity, obesity itself might lead to diminished cognitive control (Davidson et al., 2019). At the same time, lifestyle factors may amplify or modify these neural predispositions. Research suggests that diets rich in ultra-processed foods not only distort reward system functioning but also reinforce habitual overeating, creating a feedback loop that exacerbates obesity risk (Edwin and Tittgemeyer, 2020). Moreover, the interaction between behavioral patterns and reward system activity may perpetuate maladaptive eating behaviors. For instance, repetitive exposure to specific food-related cues can alter the reward system's sensitivity, maintaining disordered eating tendencies and shaping long-term dietary habits (Frank et al., 2021). So, these findings may also suggest that while neural activity in response to food cues is heightened in individuals with eating and weight disorders, its manifestation may depend on specific states (e.g., hunger) or traits (e.g., restrained eating). Furthermore, prolonged exposure to food-related cues has been linked to weakened cognitive control, potentially contributing to overeating and other maladaptive behaviors.

Several other studies have demonstrated that cognitive control weakens in individuals with obesity or dieting tendencies under prolonged exposure to triggers, leading to deteriorations in eating behavior, such as overeating (Schienle et al., 2019). Simultaneously, the anticipation of food rewards decreases attention and increases impulsivity (Schiff et al., 2021), which is supported by improvements in cognitive control when the reward anticipation is more distant. The automatic and controlled aspects of eating behavior are interrelated, and avoiding contextual triggers can improve cognitive control and lead to healthier eating behavior (Fürtjes et al., 2020). Additionally, cognitive-behavioral therapy (CBT) integrated with cognitive training exercises has shown promise in improving inhibitory control, a key factor in preventing compulsive overeating (Manasse et al., 2020). Emerging evidence also supports the effectiveness of combining cognitive training and CBT for regulating eating behaviors, including those within normative ranges (Yang et al., 2019). Additionally, interventions such as guided self-help CBT have shown potential in reducing maladaptive eating behaviors, highlighting the impact of cognitive and behavioral regulation on managing these risks (Setsu et al., 2018).

Thus, the data on the psychophysiological mechanisms of eating behavior confirms the significance of cognitive control and the reward system in regulating eating habits and their role in the development of eating disorders. Investigating evoked brain activity in food preference decisions and its relationship to eat-

ing behavior and general nutritional knowledge can provide valuable insights into the neural mechanisms underlying behind rationality of food preferences and consumption. Such an approach will be contributing to the development of more precise and personalized interventions for preventing and treating eating disorders.

Materials and Methods

The sample consisted of 40 participants aged 18 to 25 years (70% female). EEG data were collected from 26 participants aged 18 to 33 years (80% female). None of the participants reported diagnosed disorders or complaints related to eating behavior. Participation was voluntary. All participants were briefed on the study's objectives and procedures and provided written informed consent.

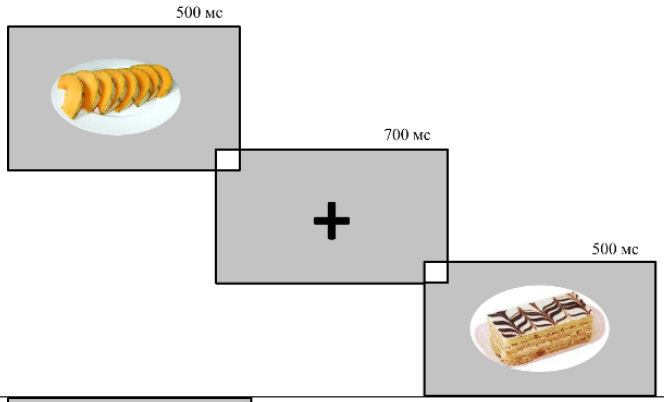
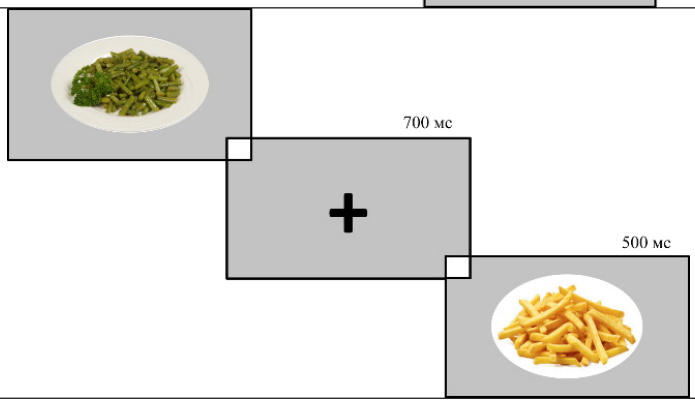
Participants were asked to report their gender, age, and answer a series of questions regarding general nutritional knowledge using the translated version of the General Nutrition Knowledge Questionnaire (Kliemann et al., 2016).

To study the psychological aspects of eating behavior, the following methods were employed: Dutch Eating Behavior Questionnaire (DEBQ) (T. VanStrien et al., 1986; Russian adaptation by I.G. Malkina-Pykh, 2007), Thoughts and Behaviors Questionnaire (TBQ) (M. Cooper, G. Todd, R. Woolrich, 2006; Russian adaptation by A.V. Anikina, T.A. and Rebeko, 2009), Three-Factor Eating Questionnaire (TFEQ) (A. Stunkard, S. Messic, 1985; Russian version, 2018).

To explore food preferences, a protocol for an experimental psychophysiological study was developed, which included two types of tasks. Computerized tasks were programmed and performed using the PsychoPy software and included high-resolution images of food items collected from the Internet (examples are shown in Table 1).

The task was modeled as a variation of the Go/NoGo paradigm. Stimuli consisted of images of various food items. The test was conducted in two series: the first series involved selecting food stimuli congruent with the participant's preferences; the second series involved selecting food stimuli incongruent with the participant's preferences. Images of various food items that matched (first series) or did not match (second series) the participant's preferences were used as target stimuli with a Go response. Each series included 150 stimuli presented in random order, with a stimulus exposure time of 500 ms.

Table 1. *Examples of stimuli by series*

Task	Example of stimulus material
2. Go-stimuli are foods congruent with participant preferences	
2. Go-stimuli are foods incongruent with participant preferences	

ERP was recorded using a "Neurovisor 136" electroencephalograph, in 128 channels (monopolar montage with A1 and A2 ear electrodes as a references). EEG data were processed using WinEEG software. For ERP pre-stimulus interval was limited to 200 ms, and the post-stimulus interval was set to 700 ms.

Statistical methods: distribution parameter analysis was conducted using the Shapiro-Wilk test. Comparative analyses were performed using the Mann-Whitney U test and Student's t-test, with effect sizes calculated using Cohen's d and biserial correlation coefficients. Additional analyses included one-way analysis of variance (ANOVA), Spearman's rank correlation coefficient, and k-means cluster analysis.

Results

To classify participants based on multiple indicators of eating behavior, a cluster analysis (K-means clustering) was conducted. The following variables were used for clustering: restrictive, emotional, and external eating behavior (Dutch Eating Behavior Questionnaire); negative, positive, and permissive thoughts; dieting and overeating; concerns about clothing, weight, and shape; food-related behaviors and the eating process (Thoughts and Behavior Questionnaire); as well as restraint, disinhibition, and hunger susceptibility (Three-Factor Eating Questionnaire). As a result, two distinct clusters were identified, differing in the severity of eating behavior traits, cognitive patterns, and behavioral aspects of nutrition. Cluster 1 (n = 25, 22 women, 3 men, mean age = 29) was characterized by low to moderate levels across these indicators, reflecting a healthy eating behavior style. Cluster 2 (n = 15, 14 women, 2 men, mean age = 29) exhibited moderate to high levels of the same indicators, suggesting a tendency toward disordered eating patterns.

Table 2. *Results of the analysis of differences between clusters based on the indicators used for clustering*

Indicator	Means		Between-group variance	Within-group variance	F	Significance level
	Cluster 1	Cluster 2				
Restrictive eating behavior	*1,94*	*2,91*	*9,30*	*23,30*	*15,57*	*0,000*
Emotional eating behavior	*1,78*	*2,59*	*6,29*	*28,47*	*8,62*	*0,006*
External eating behavior	*2,76*	*3,18*	*1,68*	*10,69*	*6,13*	*0,018*
Negative thoughts	*6,46*	*42,05*	*12360,95*	*8351,00*	*57,73*	*0,000*
Positive thoughts	*4,40*	*30,19*	*6487,76*	*5264,44*	*48,06*	*0,000*
Permitting thoughts	*22,23*	*48,57*	*6769,97*	*10269,67*	*25,71*	*0,000*
Diet	*15,00*	*30,86*	*2453,85*	*7996,00*	*11,97*	*0,001*
Overeating	*14,57*	*38,39*	*5536,76*	*4794,88*	*45,03*	*0,000*
Clothing	*12,56*	*50,88*	*14322,33*	*10627,91*	*52,56*	*0,000*
Weight and shape	*7,12*	*39,25*	*10071,58*	*10519,64*	*37,34*	*0,000*
Behavior associated with food	*17,87*	*32,08*	*1971,65*	*12728,11*	*6,04*	*0,019*
The process of eating	*17,20*	*31,09*	*1883,28*	*8466,11*	*8,68*	*0,005*
Restriction	*4,40*	*7,75*	*109,49*	*575,00*	*7,43*	*0,010*
Disinhibition	*2,88*	*6,44*	*123,47*	*244,58*	*19,69*	*0,000*
Sensitivity to hunger	*3,08*	*4,25*	*13,36*	*172,84*	*3,01*	*0,090*

In the analysis of group differences, significant variations were observed in eating behavior traits, as measured by the Dutch Eating Behavior Questionnaire (DEBQ) (Table 2). Cluster 1 displayed scores at the lower boundary of normative values for restrictive and external eating behaviors, with notably low scores for emotional eating. Restrictive eating scores (1.9) suggest that respondents in this cluster do not make intentional efforts to lose or maintain weight. Furthermore, their need for food likely aligns more closely with actual hunger cues (external eating behavior score: 2.76). The low emotional eating score characterizes this group as exhibiting a healthy eating style, without a tendency to use food as a coping mechanism for stress.

In contrast, Cluster 2 demonstrated elevated scores across all three scales of the DEBQ. The restrictive eating score (2.9) indicates a preoccupation with weight gain and attempts to restrict food intake. Higher emotional eating scores reflect a propensity to use food as a means of coping with emotional distress. Regarding external eating behavior, participants in this cluster are less guided by internal hunger signals and more influenced by external food-related stimuli when making decisions about eating.

Eating-related thought processes also significantly differed between clusters. Respondents in Cluster 1 scored low across all scales, indicating minimal engagement with negative, positive, or permissive thoughts regarding food. Conversely, Cluster 2 exhibited substantially higher scores, mostly within average ranges, suggesting a stronger tendency to associate food with guilt, loss of control, weight gain, and punishment. Permissive thoughts in Cluster 2 appeared to counterbalance negative ones, allowing participants to justify food-related behaviors.

Behavioral patterns further highlighted differences: Cluster 1 scored low across all measures, while Cluster 2 showed higher scores for behaviors such as “Clothing,” “Weight and Shape,” and “Overeating.” These scores suggest that individuals in Cluster 2 are more prone to overeating and tend to conceal their bodies with specific clothing to mask their shape.

The Three-Factor Eating Questionnaire (TFEQ) revealed notable differences between clusters as well. Cluster 1 had consistently low scores across all three factors, whereas Cluster 2 showed scores for restraint and disinhibition twice as high as those in Cluster 1, although still within the lower end of the normative range. This suggests that participants in Cluster 2 are more inclined to restrict their food intake to manage body weight and size and are also more prone to impulsive eating behaviors. The “Hunger Susceptibility” factor remained within normal limits for both groups, indicating a general ability to manage hunger and cravings in both clusters.

Considering the absence of high scores across both clusters, it can be concluded that the sample overall does not exhibit dysfunctional eating patterns.

In summary, the two groups differ significantly in the extent of restrictive, emotional, and external eating behaviors; the presence of negative, positive, and permissive thoughts; behavioral patterns; and restraint and disinhibition in eating. Cluster 1 is characterized by a healthier eating style, whereas Cluster 2 shows greater concern with weight management or reduction.

Regarding differences in general awareness and knowledge about nutrition and health, Cluster 2 showed significantly higher levels of both general awareness and specific knowledge about the effects of food on health compared to Cluster 1, which exhibited lower scores in these areas. The results of the statistical analysis are presented in Figure 1.

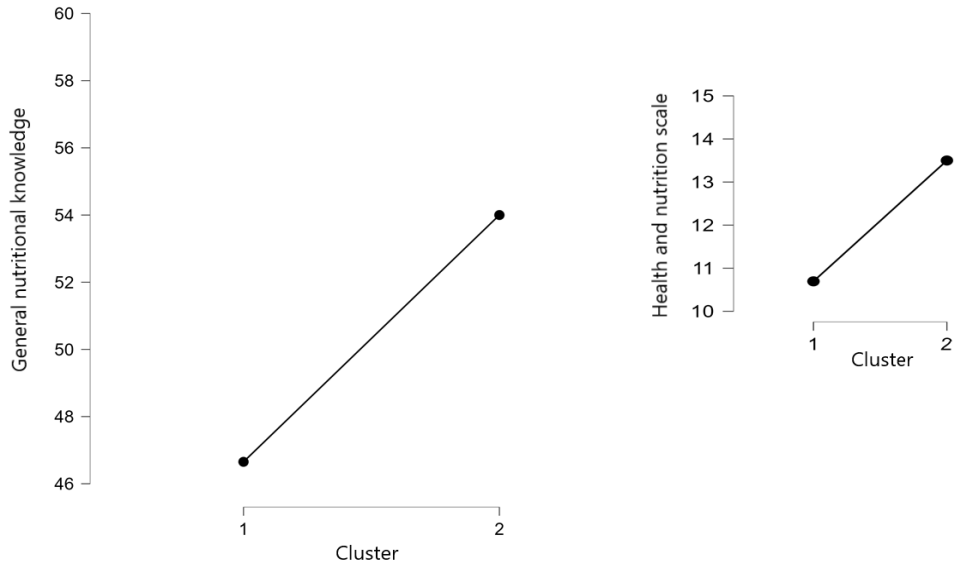


Figure 1. Differences Between Clusters in General Awareness of Nutrition and Health ($p<0.05$)

These defferences align with the hypotheses proposed earlier. The findings likely reflect the characteristics of the clusters. Since Cluster 2 is generally more concerned with weight maintenance and reduction, as well as dietary control, their higher levels of general awareness of nutrition and health may reflect a greater interest in these topics.

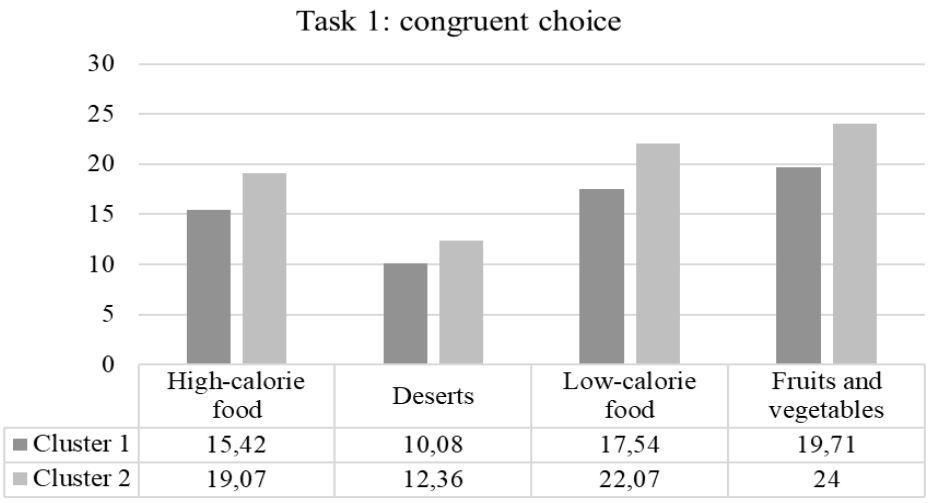


Figure 2. Analysis of Food Preferences Among Respondents

An analysis of average scores for food preferences among respondents in both clusters revealed a tendency to select healthier options, particularly vegetables and fruits. Respondents from both clusters showed the least preference for desserts (Cluster 1: 10.08; Cluster 2: 12.36). Differences in food preferences between the two clusters indicate that respondents in Cluster 2 had higher average scores across all food categories, with a particularly noticeable gap in the selection of low-calorie foods (Cluster 1: 17.54; Cluster 2: 22.07) and fruits and vegetables (Cluster 1: 19.71; Cluster 2: 24). Respondents in Cluster 2 also scored higher in their preference for fatty foods (Cluster 1: 15.42; Cluster 2: 19.07).

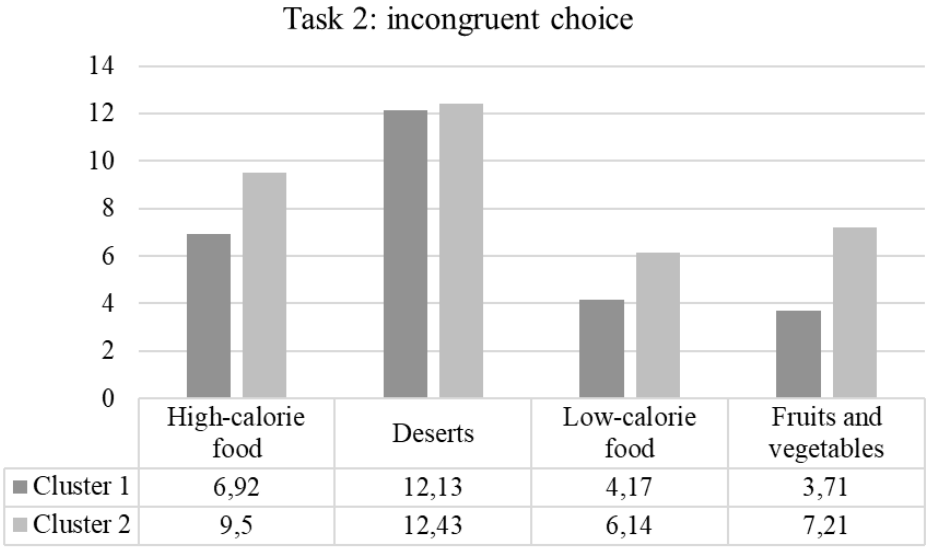


Figure 3. Analysis of Food Choices Incogruent to Preferences

When analyzing food choices that diverged from respondents' stated preferences, Cluster 2 participants again demonstrated higher average scores across all food categories. For both clusters, desserts were the least chosen items. The smallest difference between clusters was observed in desserts as a category of non-preferred food (Cluster 1: 12.13; Cluster 2: 12.43). Low-calorie foods and fruits/vegetables were less frequently chosen as non-preferred items, with Cluster 1 participants more frequently selecting low-calorie foods (Cluster 1: 4.17; Cluster 2: 6.14), while Cluster 2 participants favored fruits and vegetables (Cluster 1: 3.71; Cluster 2: 7.21). Fatty foods, as non-preferred items, were also selected more often by Cluster 2 participants than Cluster 1 (Cluster 1: 6.92; Cluster 2: 9.5).

Overall, both clusters showed a general preference for healthier food options, particularly fruits and vegetables, and the least preference for desserts. However, Cluster 2 participants displayed higher

average scores across all food categories, especially in the selection of low-calorie foods and fruits/vegetables. These findings suggest that respondents in Cluster 2 are inclined toward more differentiated food choices, which aligns with the overall characteristics of the cluster.

Heatmap analysis revealed higher amplitudes of evoked potentials during congruent food choice tasks in the first series for Cluster 2 participants. These increased amplitudes were observed in early- and mid-latency components across all types of stimuli (Figure 4).

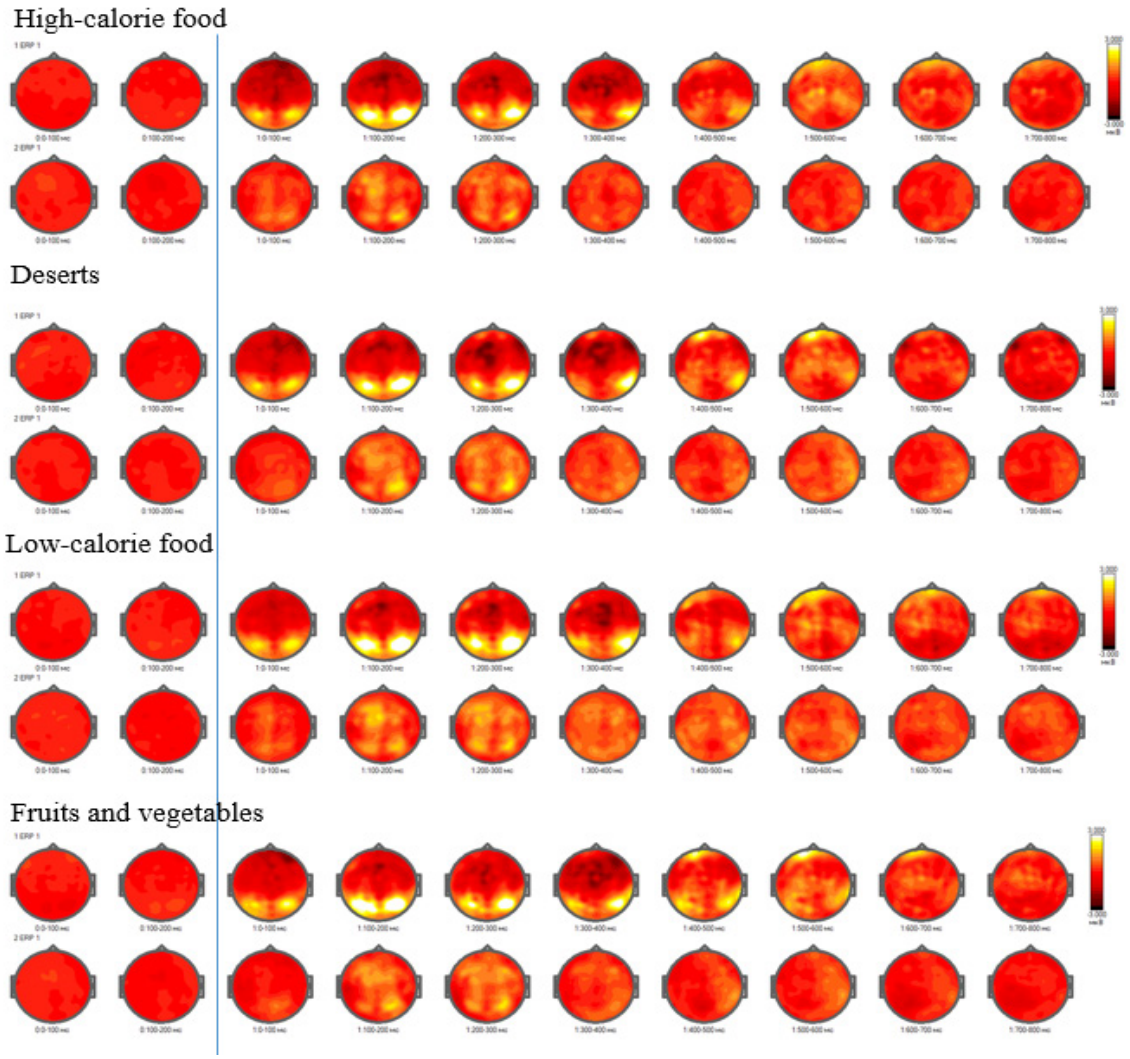


Figure 4. Temporal Dynamics of Average Amplitude of Evoked Potentials (EP) in Food Preference Task 1 in Clusters Based on Psychological Eating Behavior Characteristics (Cluster 1 - Bottom Row, Cluster 2 - Top Row)

Statistically significant differences between the clusters were found in tasks involving congruent food choices. When accessing low-calorie dishes, differences were observed in the central-parietal region at 100–200 ms, in the central and temporal regions at 200–300 ms, in the left frontal area at 300–400 ms, and in the left fronto-central region at 400–500 ms. Similar differences were noted when viewing dessert images, with distinctions appearing in the temporal region at 100–200 ms, in the central, parietal, and frontal regions at 200–300 ms, in the frontal region at 300–400 ms, and in the left fronto-temporal and fronto-central regions at 400–500 ms. For fruits and vegetables, significant differences emerged in the occipital region at 100–200 ms, in the temporal regions at 200–300 ms, in the temporal region and a single frontal electrode at 300–400 ms, and at single electrodes in the left fronto-central region at 400–500 ms. In response to high-calorie foods, differences were detected in the central-parietal region at 100–200 ms, in the central-frontal and parietal regions at 200–300 ms, in the left frontal area at 300–400 ms, and in the left fronto-central and right fronto-temporal regions at 400–500 ms.

The observed temporal and topographical differences in processing various food types (low-calorie,

high-calorie, desserts, fruits, and vegetables) suggest variability in cognitive and emotional responses depending on the food category. More pronounced differences in the temporal and frontal regions for desserts and high-calorie foods may indicate greater involvement of reward-related and cognitive control areas.

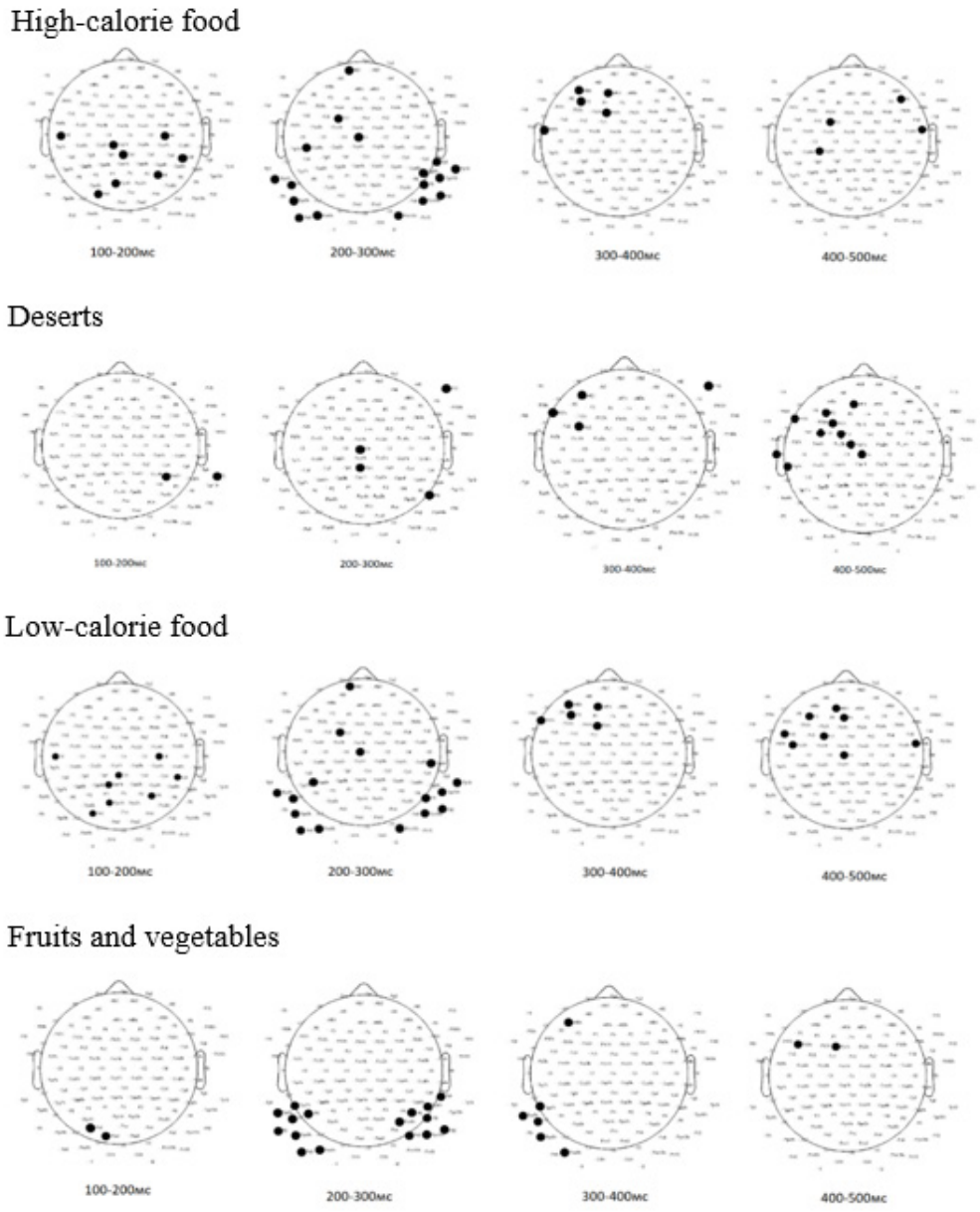


Figure 5. Analysis of Differences in Average EP Amplitude in Food Preference Task 1 in Clusters Based on Psychological Eating Behavior Characteristics ($p<0.05$)

When performing the task of making food choices incongruent with dietary preferences in the second series, a higher amplitude of evoked potentials (EP) of early and middle latency was also observed in the second cluster, regardless of stimulus type (Figure 6).

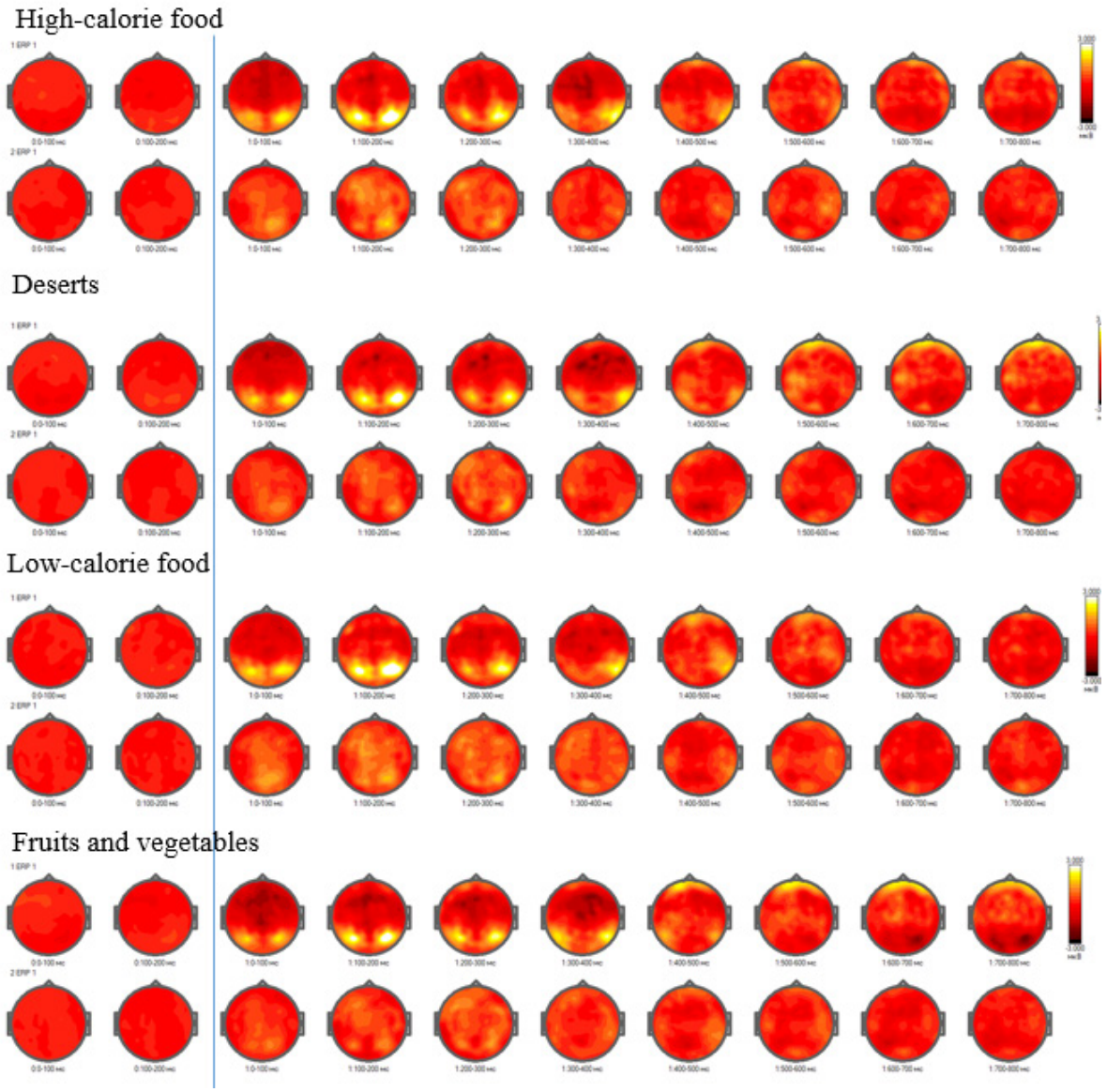


Figure 6. Temporal Dynamics of Average Amplitude of Evoked Potentials (EP) in Food Preference Task 2 in Clusters Based on Psychological Eating Behavior Characteristics (Cluster 1 - Bottom Row, Cluster 2 - Top Row)

Statistically significant differences between clusters were identified during the task of making food choices incongruent with individual preferences for specific stimulus types. High-calorie food images elicited differences at 100–200 ms in the central-parietal and left temporal regions. The 200–300 ms interval showed differences in the frontal-central, left temporal, and temporo-parietal regions. Between 300 and 400 ms, significant activity appeared in the left frontal and central regions, while the 400–500 ms interval involved the left frontal-temporal region and a single right frontal-temporal channel. For dessert images, no differences were observed at 100–200 ms; however, significant activity emerged during the 200–300 ms interval in the central, left-lateralized frontal, and parietal regions, followed by activity in the frontal region at 300–400 ms and the left frontal-central and temporal regions at 400–500 ms. Low-calorie food images showed differences during the 100–200 ms interval in the central-parietal region. At 200–300 ms, significant activity was detected in the left-lateralized frontal, central, and temporal regions. By 300–400 ms, activity persisted in the frontal and central regions, with left lateralization, and at 400–500 ms, in the left frontal-temporal region. For fruits and vegetables, differences were first noted during the 100–200 ms interval in the central-parietal region. Subsequent differences were observed at 200–300 ms in the left-lateralized frontal, central, and temporal regions, followed by activity at 300–400 ms in the left-lateralized frontal and central regions, and at 400–500 ms in the left frontal-temporal region.

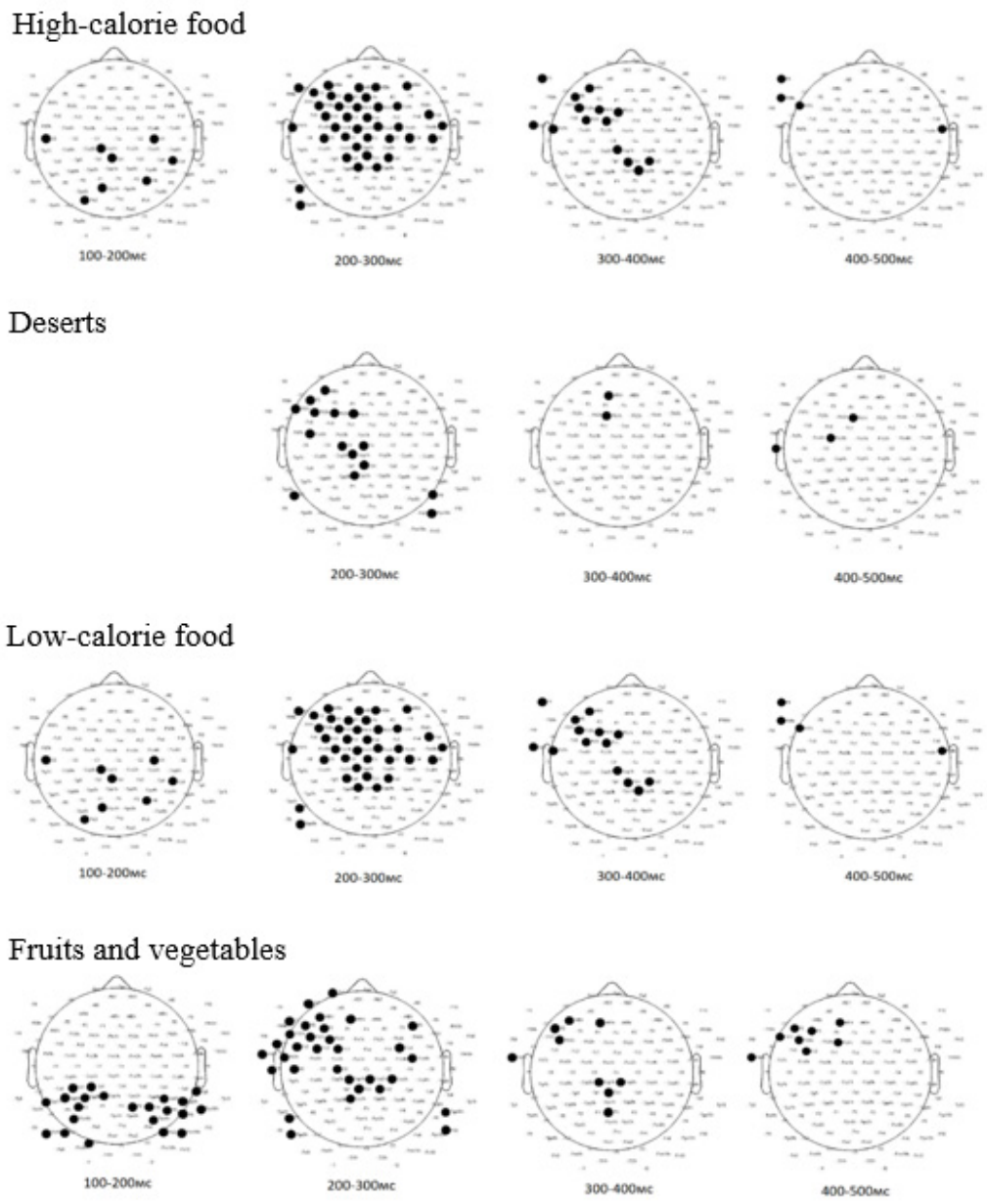


Figure 7. Analysis of differences in averaged EP amplitude values in Food Preference Task 2 in Clusters Based on Psychological Eating Behavior Characteristics (p<0,05)

Overall, significant differences between clusters identified by eating behavior traits were predominantly observed in the temporo-occipital regions across all stimulus types. For high-calorie food, Cluster 1 showed higher amplitudes during early processing stages (100–200 ms), while Cluster 2 exhibited greater amplitudes at later intervals (200–300 ms and 400–500 ms). For low-calorie food and fruits/vegetables, significant differences were primarily localized in the parietal-occipital regions, with Cluster 1 demonstrating consistently higher amplitudes in early intervals (100–300 ms). These findings suggest distinct neural processing patterns between clusters, reflecting differences in attentional or evaluative responses to food stimuli. These findings highlight the role of cognitive control and attentional modulation in decisions that deviate from habitual food preferences, reflecting their importance in regulating eating behavior.

Next, to test the hypothesis that brain activity characteristics in food preference choice tasks may differ depending on the level of awareness in nutrition and health, a comparative analysis was conducted between the group with above-average results (group 1) and the group with below-average results (group 2). Respondents with average results were excluded from the sample during the calculations.

Visual differences between the heatmaps of the groups with different levels of awareness in nutrition and health are minimal. However, an increase in the amplitude of event-related potentials (ERPs) was observed in the first group of participants, characterized by higher levels of awareness, in the occipital area between 100-400 ms during the first series, regardless of the type of stimulus (Figure 8).

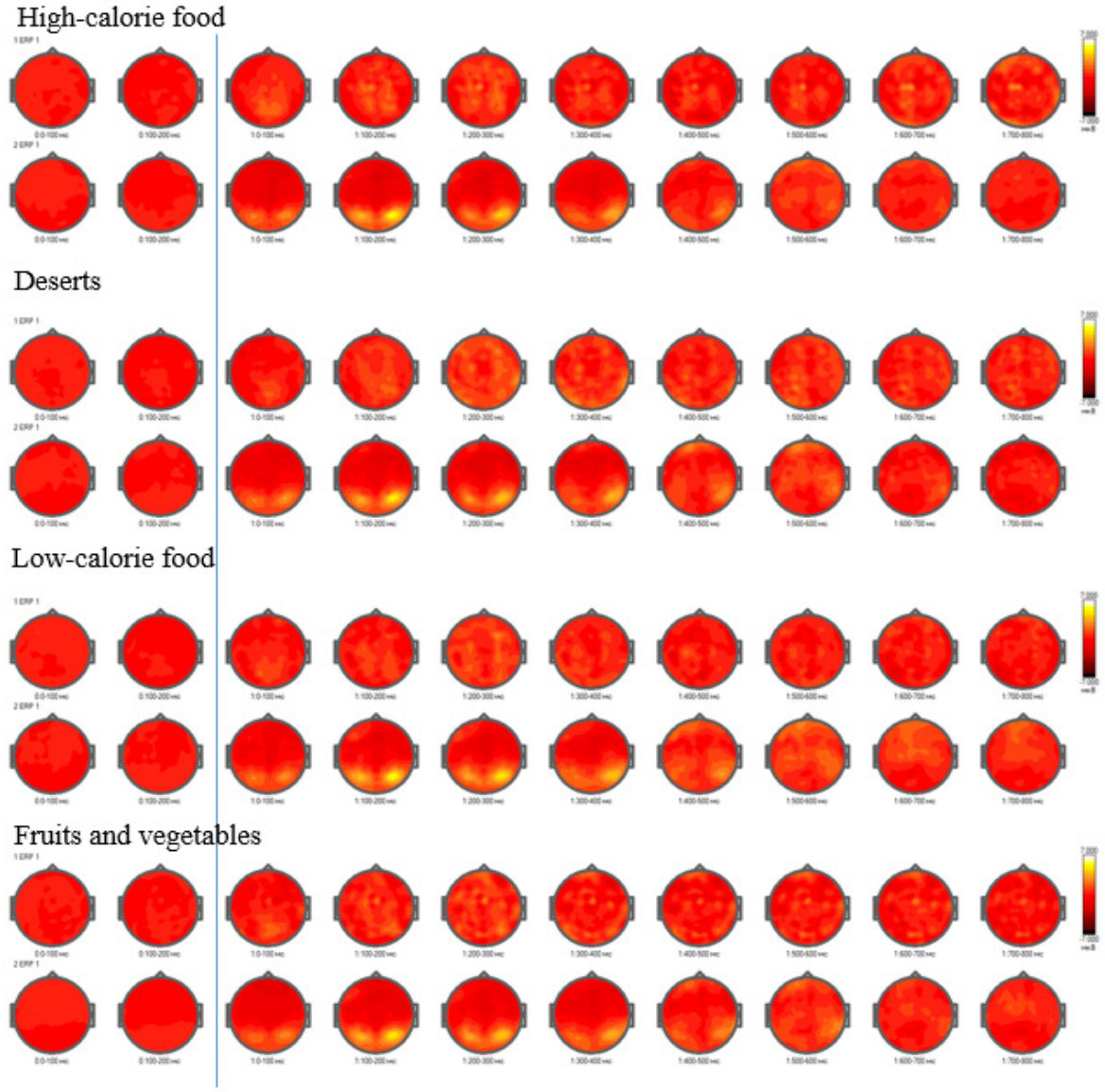


Figure 8. Temporal Dynamics of Average Amplitude of Evoked Potentials (EP) in Food Preference Task 1 in groups depending on the level of awareness in nutrition and health (results for group 1 in the lower row of images, for group 2 in the upper row).

Since the distribution in the selected groups for several indicators differed from normal (Shapiro-Wilk test), the analysis was conducted using both a parametric criterion (Student's t-test) and a non-parametric criterion (Mann-Whitney U-test). Significant differences between the first and second groups in the congruent food choice task during the first series, when demonstrating images of high-calorie foods, were found in the 100-200 ms interval in the temporal areas, in the 200-300 ms interval in the left and right temporal areas, and in the 400-500 ms interval in the left central-temporal area. No statistically significant differences were found in the 300-400 ms interval (Figure 9).

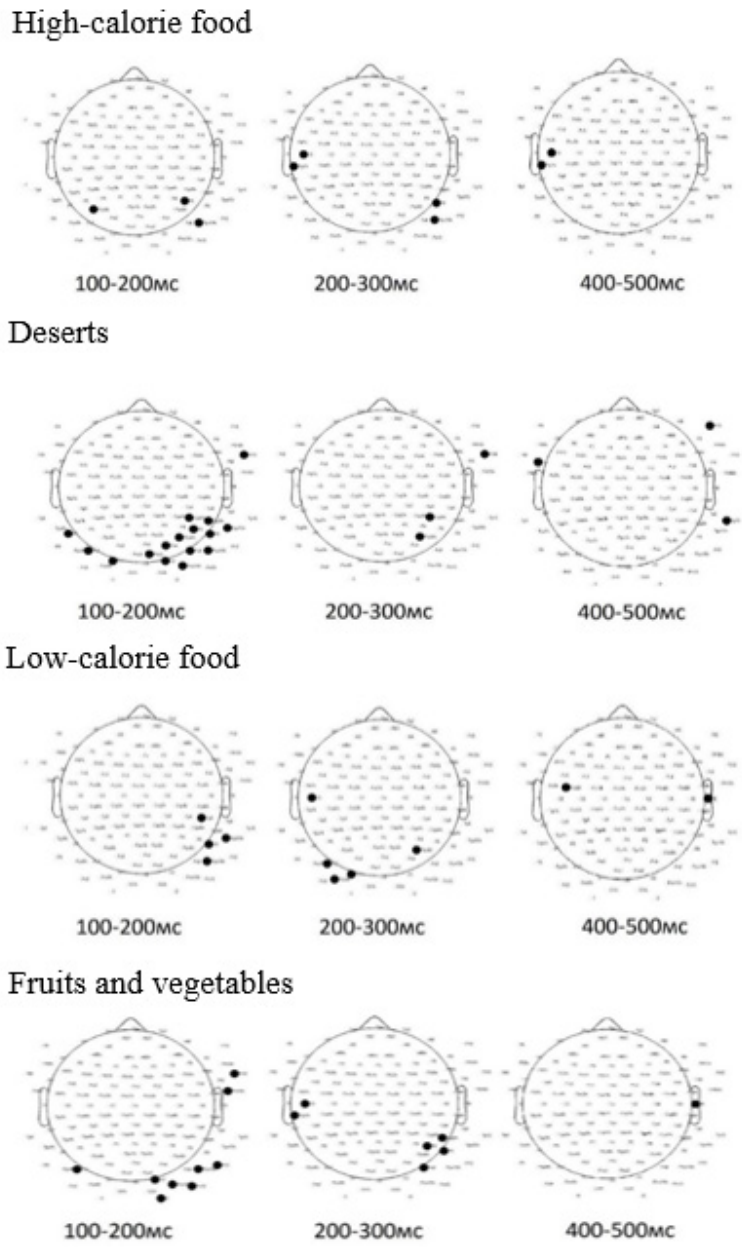


Figure 9. Analysis of Differences in Average EP Amplitude in Food Preference Task 1 in groups depending on the level of awareness in nutrition and health ($p < 0.05$).

Statistically significant differences in averaged ERP amplitude values across participant groups depending on the level of awareness in nutrition and health were predominantly localized in the temporo-occipital regions. For dessert images at 100–200 ms, differences emerged in the parietal-occipital regions, in the 200–300 ms interval, significant activity was detected at a single electrode in the fronto-temporal and temporal regions, while at 400–500 ms, differences were observed in the left temporo-parietal, fronto-temporal, and right frontal regions. For low-calorie dishes, significant differences appeared at 100–200 ms in the right temporo-parietal region. During the 200–300 ms interval, differences were noted at individual electrodes in the central, parietal, and left parieto-occipital regions. By 400–500 ms, significant differences were observed at individual electrodes in the temporal and fronto-central regions. When fruits and vegetables were presented, differences were observed at 100–200 ms at individual electrodes in the left parieto-occipital, fronto-temporal, and right parieto-occipital regions. At 200–300 ms, significant activity was seen in the left centro-temporal and right parieto-occipital regions. Finally, during the 400–500 ms interval, differences were observed at a single electrode in the right temporal region.

In the second task, the heatmaps also show an increase in the amplitude of the P300 in the occipital region during the 100-300 ms interval for the first group of participants (Figure 10).

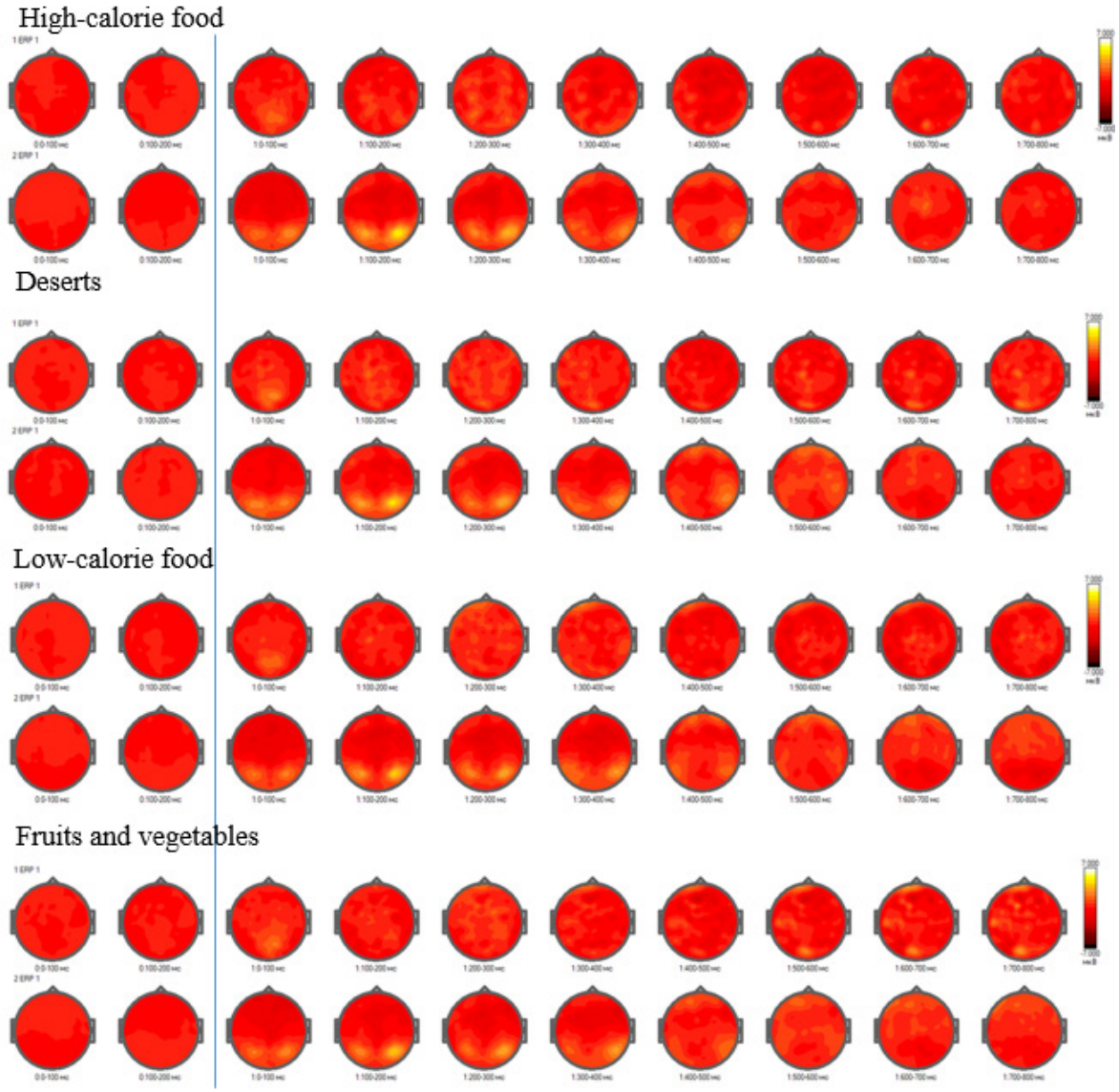


Figure 10. Temporal Dynamics of Average Amplitude of Evoked Potentials (EP) in Food Preference Task 2 in groups depending on the level of awareness in nutrition and health (results for group 1 in the lower row of images, for group 2 in the upper row).

Statistically significant differences in ERP amplitude between the first and second groups during the incongruent food choice task were predominantly observed in temporo-occipital regions (Figure 11).

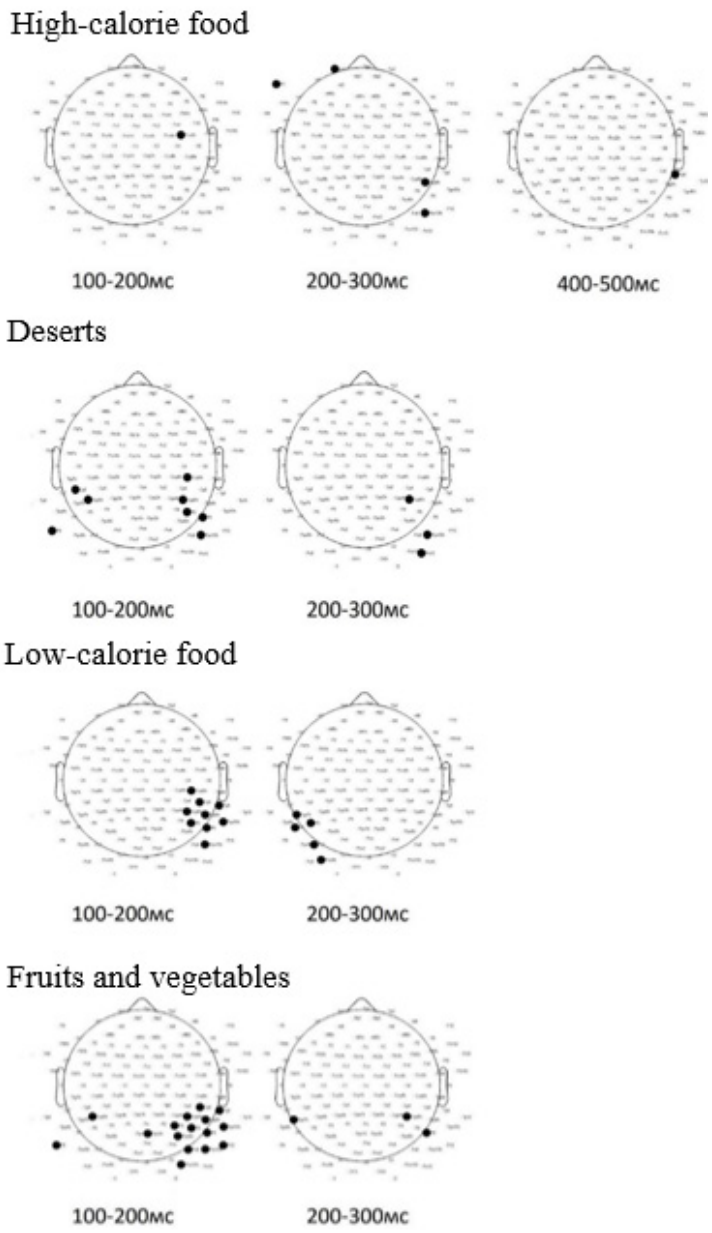


Figure 11. Analysis of Differences in Average EP Amplitude in Food Preference Task 2 in groups depending on the level of awareness in nutrition and health ($p<0.05$).

For high-calorie food, significant differences were found at 100–200 ms in the fronto-central region (single electrode), at 200–300 ms in the left frontal and right temporo-occipital regions, and at 400–500 ms in the right temporo-parietal region, with no differences at 300–400 ms. For desserts, differences were detected at 100–200 ms in the left and right centro-parietal regions and at 200–300 ms in the right parieto-occipital region, with no significant differences at 300–400 ms or 400–500 ms. For low-calorie food, differences appeared at 100–200 ms in the right temporo-central region (single electrode) and at 200–300 ms in the left parieto-occipital region, with no differences observed at later intervals. For fruits and vegetables, significant differences were observed at 100–200 ms in the left parietal, centro-parietal, temporo-parietal, and parieto-occipital regions, and at 200–300 ms at single electrodes in the left and right temporo-parietal regions, with no significant differences at 300–400 ms or 400–500 ms.

So, differences between groups with varying levels of nutritional and health awareness were primarily observed in temporo-occipital regions across both series. In the first series, higher amplitudes were noted in the more aware group during early stages of stimulus processing (100–400 ms), while the less aware group exhibited higher amplitudes at later stages (400–500 ms), regardless of stimulus type. In the

second series, the less aware group showed higher amplitudes at 100–200 ms and 400–500 ms for high-calorie food, whereas the more aware group demonstrated higher amplitudes at 100–200 ms (excluding high-calorie food) and 200–300 ms, irrespective of stimulus type.

Discussion

The results of this study confirm the importance of psychophysiological mechanisms in the regulation of eating behavior and their relationship with psychological factors, as well as with the level of general awareness in nutrition and health. The obtained data, demonstrating differences in the characteristics of brain activity between the identified clusters and respondent groups, align with findings from previous research. For instance, the observed differences in the average P300 amplitude during the 200–300 ms interval between clusters support earlier evidence linking cognitive control, impulsivity, and food preferences. The observed activation in the fronto-central region during the 600–700 ms interval, particularly in response to non-food stimuli, highlights the role of cognitive control in suppressing impulsive reactions.

Additionally, the more pronounced activation of the temporal-occipital region in participants with a higher level of nutritional awareness aligns with the idea that greater awareness may facilitate heightened attentional processing of food-related stimuli. However, the relatively limited number of statistically significant differences associated with the level of awareness could reflect the small sample size or lend support to the hypothesis that psychological traits (such as impulsivity or cognitive control) outweigh knowledge levels in determining food preferences and potentially in shaping these preferences.

The findings for the second cluster, characterized by heightened sensitivity to external food stimuli, further support the hypothesis that excessive responses to food triggers may be associated with insufficient cognitive regulation. This aligns with prior evidence suggesting that individuals who exhibit strong external sensitivity may struggle with attentional control or emotion regulation in food-related contexts.

Several limitations should be noted. The small sample size may reduce the statistical power of the results, and the inclusion of individuals without diagnosed eating disorders limits the generalizability of these findings to clinical populations. While this approach provides valuable insights into eating behavior in the general population, its applicability to groups with clinical concerns remains unclear.

In conclusion, this study emphasizes the importance of a comprehensive approach to examining food preferences, integrating cognitive, emotional, and neurophysiological factors. Future research should aim to expand sample sizes, include clinical populations, and investigate the interplay between knowledge, psychological traits, and neurophysiological responses in greater detail.

Conclusion

The aim of this study was to investigate the characteristics of brain activity in food preference tasks, depending on psychological characteristics of eating behavior, as well as the level of general awareness in proper nutrition.

The identified differences between the clusters indicate that respondents with healthier eating behaviors demonstrate lower reactivity to external food stimuli, which is related to a higher level of cognitive control. In contrast, respondents with less healthy eating behaviors are characterized by increased sensitivity to external triggers, which supports the significance of psychophysiological mechanisms in regulating behavior.

Overall, the differences in brain activity between the first and second clusters, depending on the psychological characteristics of eating behavior, and between the identified groups of respondents, depending on their level of awareness in nutrition and health, in tasks involving congruent and incongruent food preference choices, are aligned with both the characteristics of the studied groups and the type of tasks performed.

The obtained results may be useful for creating prevention and treatment programs for eating behavior disorders, tailored to the individual characteristics of respondents, and open up opportunities for further study. In particular, it is important to investigate the nature of the relationship between cognitive control indicators and various aspects of eating behavior, and whether different forms of interventions aimed at developing executive functions can influence long-term changes in eating habits.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, E.P.N.; formal analysis, G.A.O.; investigation, K.D.R. and S.N.V.; project administration, D.E.G.; supervision, E.P.N; writing – original draft, D.E.G., K.D.R. and S.N.V.; writing – review & editing, D.E.G. and K.D.R. All authors have read and agreed to the published version of the manuscript.

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Impact of Peer Feedback in a Web Programming Course on Students' Achievement

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Abstract: In addition to learning technical aspects of website creation, students must connect different knowledge, think critically, seek more information, and approach their work from various perspectives. These requirements, or specified competencies, can be developed through providing and receiving peer feedback, which is confirmed as an efficient learning strategy in various empirical studies on different subjects. The aim of this research is to investigate the impact of peer feedback on students' achievements in the Web Programming Course. We conducted a quantitative study with two groups of students. Students from the experimental group participated in online giving and receiving peer feedback regarding students' assignments, while students from the control group did not have this opportunity. For evaluating students' work, we used rubrics. The results indicate that students, through analyzing their peers' work, providing qualitative assessments, reflecting on their work in line with received comments, and making necessary corrections, create content that surpasses the quality of websites created by their peers who did not have the opportunity to participate in peer feedback activities. Since students extensively analyzed their work after receiving comments and suggestions, made specific corrections, and consequently improved their projects, organizing peer feedback activities in programming courses, especially web programming, should be given more attention.

Keywords: *peer feedback, web programming, students' achievements, higher education.*

Introduction

Traditionally, the main aim of assessment is to determine to what degree students have achieved the expected learning objectives by the end of the teaching period. Recent assessment approaches have moved away from the explicit focus on end-of-the-course (i.e., summative) testing to in-course (i.e., formative) assessment (Rotsaert, 2017; Sudakova et al., 2022). This shift from a testing culture to an assessment culture (Birenbaum, 2003), which makes assessment an integral aspect of learning, is better known as the 'assessment for learning' position (Black and Wiliam, 1998).

Formative assessment has a rather student-centered character. Instead of contributing to final grades, formative assessment aims to provide support and feedback, allowing students to monitor their learning progress and identify their strengths and weaknesses (Ashenafi, 2015). While the importance of formative assessment is stressed by several authors (e.g., Falchikov and Goldfinch, 2000; Carless, 2007), traditional assessment systems still seem to dominate the higher education scene (Cañadas, 2020).

Peer assessments can be formative, summative, or a combination of both (Dunn and Mulvenon, 2010; Topping, 2010a). Based on the work of Topping (1998), Strijbos and Sluijsmans (2010, p. 266) define peer assessment as "an educational arrangement where students judge peer's performance quantitatively, by providing the peer with scores or grades, and/or qualitatively, by providing the peer with written or oral feedback." In this paper, we explore the use of peer assessment, which Strijbos and Sluijsmans (2010) describe as a progressive and formative form of assessment, in an Introduction to Web Programming course.

Several benefits of peer assessment can be found in the literature. In line with society's growing demand for more responsible, critical, and thoughtful professionals in the labor market, an activity in which

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students are challenged to assess fellow students' work would help them to learn, among other things, how to criticize constructively and strengthen important cognitive dimensions such as critical thinking (Wang et al., 2012). Peer evaluation is extremely important for strengthening critical thinking for students. It allows students to learn the process of evaluating their work but also to strengthen the skill of giving comments and suggestions assertively. Also, this is a skill that is necessary for teamwork, and it is very useful to practice developing it in the higher education process.

Research reports and case studies that examine peer review in the context of teaching programming have, in most cases, positive conclusions. Peer-reviewing enables students to critically analyze the work of their peers (colleagues). The opportunity to see and analyze different solutions can bring new ideas to students and help them view their work more thoughtfully. This gives the potential for improvement of programming courses in higher education, where the quality of the solutions is often measured (Loll and Pinkwart, 2009; Reily, Finnerty, and Terveen, 2009). In the case of student assessment in programming courses, peers could be exposed to various styles of coding and asked to give evaluations of their colleagues' work, which allows students to improve their proficiency as programmers and deepen their understanding.

With this paper, we aim to contribute to the existing scientific literature that explores the significance and effects of peer feedback, specifically its application in an Introduction to Web Programming course with computer science students. Additionally, we seek to provide a practical contribution to the teaching of programming-related courses, to improve the teaching process and enhance the knowledge and competencies of students, who are future professionals in this field.

The paper is organized as follows: The second section presents findings from the literature, specifically on peer review, peer assessment, and peer feedback. The third section outlines the research question and hypothesis. The fourth section describes the research methodology, including the sample, of Introduction to Web Programming course characteristics, and the research procedure. The fifth section presents the results of the study, comparing the achievements of a group of students who engaged in peer feedback as part of their course projects with those of a group who did not have this opportunity. In the sixth section, the findings are discussed in the context of previous related research. Finally, the seventh section provides conclusions and pedagogical implications.

Theoretical background

The concepts of peer review, peer assessment, and peer feedback are closely interconnected and complement each other to a significant extent. In this section, we will describe their characteristics from the perspective of researchers who have explored these topics.

Peer review

The instructional aim of peer review with a feedback learning strategy is to enhance higher-level thinking by mutually exchanging critiques among peers (students). In the traditional process, students receive comments from the teacher, and in the peer review process, review comments are received from peers. Therefore, peer pressure may encourage students to perform higher-level cognitive functions (Topping, 1998). During the peer review process, students expressed higher-level thinking such as critical thinking, planning, monitoring, and self-regulation (Liu, Chiu, and Yuan, 2001). In the peer-reviewing process, beneficiaries are simultaneously the students who learn from others' solutions and receive feedback and the teachers who can get assistance for the evaluation. In this manner, students may find peers' solutions interesting because it can give them new ideas and a chance to learn analytical abilities from varying styles of solving problems (Diefes-Dux and Verleger, 2009).

Peer Assessment

The term assessment is often interpreted as referring to marking, grading, measuring, or ranking. Consequently, peer assessment is usually regarded as students giving marks or grades to each other. Peer assessment is about getting and giving feedback, not about giving grades. It is the process whereby groups of individuals rate their peers. To overcome social relationship problems, feedback is best given online rather than in class because students tend to be more forthcoming and constructive in an online environment (Liu and Carless, 2006).

Advocates for peer assessment argue that regular feedback on learning not only contributes to skill development but also motivation for learning (Topping, 2009; Topping, 2010a; William, 2011). For peer assessment to be considered effective, goals, practices, and outcomes of the practice must align. Student involvement in assessment appears to have been increasing in recent years. This increase appears across the spectrum of discipline areas, including science and engineering, arts and humanities, mathematics, computer science and education, social sciences, and business. Peer assessment is grounded in philosophies of active learning (e.g., Piaget, 1971) and may also be seen as a manifestation of social constructionism (e.g., Vygotsky, 1962), as it often involves the joint construction of knowledge through discourse. An important educational function of peer assessment is the provision of detailed peer feedback (Falchikov, 1994, 1995, 2001).

The benefits of peer assessment may only be realized after a serious effort is made to incorporate it into everyday teaching practices in a way that is positive, non-threatening, and attractive to students (Sluijsmans, Brand-Gruwel, and van Merrienboer, 2002).

Formative assessment by Cizek (2010) represents "the collaborative processes engaged in by educators and students to understand the students' learning and conceptual organization, identification of strengths, diagnosis of weaknesses, areas of improvement, and as a source of information teachers can use in instructional planning and students can use in deepening their understanding and improving their achievement." In defining 'assessment for learning', Black, Harrision, Lee, Marshall, and Wiliam (2004) include any action that provides information that teachers and their students can use as feedback in assessing themselves and one another and in modifying the teaching and learning activities in which they engage. In discussing formative peer assessment, Falchikov (1995) stated that peer assessments can focus on either the assessment of a product, such as writing, or the performance of a particular skill. This exercise may or may not entail previous discussion or agreement over criteria. It may involve the use of rating instruments or checklists, which may have been designed by others before the peer assessment exercise or by the user group to meet their needs. For Topping (2009), peer assessment is an arrangement for learners to consider and specify the level, value, or quality of a product or performance of other equal-status learners (peers). Peer assessments appear to enhance the intrinsic motivation of students, and this form of assessment offers opportunities for students to learn outside the conventional pattern of student-teacher interaction (Falchikov, 2003).

Peer feedback

Peer feedback refers to a collaborative activity between at least two peers (Kollar and Fischer, 2010). It is a reflective engagement that impacts the work performed by both the giver and the receiver (Falchikov, 2003). When peers are engaged as the agents for feedback, students benefit from the process, as the opportunity to observe and compare peers' work could lead to work improvement (Chang, Tseng, and Lou, 2012). Some research studies are proposed to understand how to deliver feedback in the best way possible, especially in providing constructive feedback that provides direction for improvement (Fong et al., 2021). Feedback is a consequence of the expertise and performance of a student, as well as aims of reducing the discrepancy between the current and desired level of performance or understanding. Furthermore, different agents provide different forms of feedback, and perceptions of the usefulness of feedback depend both on the content of the feedback as well as on the provider of that feedback (Evans, 2013). Feedback needs to provide information specifically relating to the task or process of learning that fills a gap between what is understood and what is intended to be understood. Winne and Butler (1994) provided an excellent summary in their claim that "feedback is information with which a learner can confirm, add to, overwrite, tune, or restructure information in memory, whether that information is domain knowledge, meta-cognitive knowledge, beliefs about themselves and tasks, or cognitive tactics and strategies" (Winne and Butler, 1994).

There are two approaches to peer feedback: asynchronous and synchronous. In an asynchronous approach, the focus is on exclusively giving peer feedback without the need to act upon the feedback; in a synchronous approach, it involves iterative dialogues among students that could be induced by the given feedback (Adachi, Tai, and Dawson, 2018). Traditional face-to-face feedback occurs in a classroom setting, while online feedback could be text messages sent by the giver to the recipient via a technology platform (Liu, Du, Zhou, and Huang, 2021). Formative peer feedback can be given quantitatively (using a

number to grade), qualitatively (verbal or text-based), or both (Topping, 2017). Specific feedback is more effective than unspecific or generalized feedback (Fong et al., 2021; Park, Johnson, Moon, and Lee, 2019). Being specific in the feedback comments implies elaborations in correction, confirmation justification, questioning, or suggestions that follow simple verifications (Alqassab, Strijbos, and Ufer, 2018).

Peer feedback thus provides the student with a broader scope of skills, but it also has some other advantages. Research on peer feedback suggests that involving students in the process of giving feedback improves the effectiveness of formative assessment and supports the learning process and outcomes (Lu and Bol, 2007). To provide good-quality feedback, that is, feedback that the receiver can use to effectively enhance their learning, a minimum level of domain and content knowledge (Geithner and Pollastro, 2016) and problem-solving skills are required.

Researchers suggest that anonymity within the peer feedback process may encourage student participation and reduce insecurity when giving feedback by reducing peer pressure (Raes, Vanderhoven, and Schellens, 2015). For example, Raes, Vanderhoven, and Schellens (2015) investigated the effects of increasing anonymity using emerging technology. These researchers showed that anonymous peer feedback through a digital feedback system combines the positive feelings of safety by being anonymous with the perceived added value of giving peer feedback. In that manner, the anonymity of the feedback thus seems to influence the way the message is received and processed. Interaction between learners is a critical part of learning in many domains, including computer programming (Warren, Rixner, Greiner, and Wong, 2014).

Feedback by itself may not have the power to initiate further action. Effective feedback must answer three major questions asked by a teacher and/or by a student: What are the goals? What progress is being made toward the goal? What activities need to be undertaken to make better progress? These questions correspond to notions of feed-up, feedback, and feed-forward (Hattie and Timperley, 2007).

For the provider of peer feedback, it helps to improve students' higher-level learning skills (Davies and Berrow, 1998), critical thinking (Ertmer et al., 2007; Lin, Liu, and Yuan, 2001), creating new concepts and connecting to what students already knew (Nicol, 2009). Van Popta, Kral, Camp, Martens, and Simons (2017) and Ion et al. (2019) suggested that providing feedback triggers several cognitive processes, such as comparing and questioning ideas, evaluating, suggesting modifications and reflection, planning and regulating one's thinking, thinking critically, connecting to new knowledge, explaining, and taking different perspectives. Regarding the reliability of the students' peer feedback, Falchikov and Goldfinch (2000) carried out a meta-analysis of 48 quantitative peer assessment studies that compared peer and teacher marks, demonstrating that students are generally able to make reasonably reliable judgments.

When it comes to programming assignments, students found the use of peer-reviewing systems for programming projects useful (Hämäläinen, Hyyrynen, Ikonen, and Porras, 2011). They say that feedback indicates that reviewing others' code and receiving comments is helpful, but that the numerical feedback given by the students and teachers was clearly on different scales, which leads us to think that evaluation criteria must be defined more clearly, and evaluations should also be rated. More attention must also be paid to providing written feedback, which is considered the most valuable part by the students (Hämäläinen, Hyyrynen, Ikonen, and Porras, 2011). Examining a Web-Based Peer Feedback System in an Introductory Computer Literacy Course Peer feedback, in which peer learners reflectively criticize each other's performance according to pre-defined criteria electronically or face-to-face, is used in peer assessment, but mainly for formative use, and it enhances the quality of the learning process (Pavlou and Kyza, 2013).

Research question

In our research, the main question is: Does the application of the web-based peer feedback process contribute to better students' achievements in creating websites on the given topic?

We expect that after thoroughly analyzing the work of their peers, gaining new ideas, and approaching problem-solving from different angles, students will make a critical review of their work and think about how they could improve their product for the project assignment, i.e., their website.

Thus, the hypothesis for the research question is: The use of the web-based peer feedback process contributes to better students' achievements in creating websites compared with the achievements of students who did not have the opportunity to analyze their peer work and make a critical review of their work based on the comments and suggestions written by their peers.

Materials and Methods

Participants

The research was conducted on 95 students in their first year of bachelor studies at the Department of Computer Science at the Faculty of Science and Mathematics in Niš, Serbia. The study took place over the academic years 2021/2022 (n=43) and 2022/2023 (n=52), and all participating students attended the "Introduction to Web Programming" course for the first time.

Course description

The "Introduction to Web Programming" course is designed in such a way that students first pass the pre-exam requirements in the amount of 65 points and then the oral exam in the amount of 35 points. In the pre-exam obligations, students' project assignments are an obligatory part. The project assignment is based on practical work, where each student individually creates a website (in the following text, we will use the terms website and project assignment equally). The maximum value of the project is 20 points, which represents 20% of the total number of points in the course. That is slightly more than 30% of the points that the student can achieve on the pre-examination requirements of this course. The knowledge that is needed in creating a project is largely acquired in lectures and exercises on the subject "Introduction to Web Programming." However, for the highest quality project, it is necessary for students to independently research, use adequate literature, and especially use Internet resources in the proper way for which they were trained during the course.

Students were randomly assigned one of thirty different project topics, and their assignment was to create a website on the given topic to simulate a real-life situation. In real life, an employee receives a client who comes with a request and an already predetermined topic. The list of project topics is very diverse, and some of the topics are travel agencies, flower shops, airline companies, IT companies, pet shops, marketing agencies, law offices, school/college websites, dental offices, hair salons, event planner, taxi association, cinema, car showroom, etc.

Students complete this assignment individually, and by doing so, they are expected to consider the theoretical and practical knowledge transferred during the lectures and seminars. Students should be the ones who design the appearance and functionality of the website. The lecturers motivate the students to be creative and research-oriented in the realization of the project. With this approach, students become active project-bearers, have responsibilities, and organize their tasks and their own time.

The research procedure

During the year 2022 of the research study, 43 students participated in the research. At the beginning of the course, all the practical information and course expectations were communicated, including the assessment criteria for the realization of the website. As they continuously gain knowledge during the course, they can upgrade their project every week, and the deadline for the final submission of the project is 7 days after the end of the course. In 2022, no peer assessment activity was linked to the realization of the website, so this group of students is seen as the control group in this study.

During 2023, 52 students participated in the course and the research. We will name these 52 students and their projects as the experimental group. Similarly to the first year of research, in the second year of research, students received a clear plan and programme for the distribution of points. After the first month of the course, each student was randomly assigned a project topic. The deadline for submitting the final project remained the same, which was 7 days after the end of the course. After the students had submitted their projects, the teaching assistant divided the students into groups of four. The moment of submission determined to which group the student belonged; the first four assignments were placed in the first group, and so on. As 52 projects were submitted in the second year of research, the students were divided into 13 groups of 4 members. Each group of students got their appointment, where each of the students had the opportunity to present their project to colleagues from their group and to the teaching assistant. After the presentation session, each member of the group had the task of assessing the work of the three other colleagues in the group by writing feedback to peers. The assessment was done anonymously by filling out a form through a series of questions (see Appendix 2). For each of the questions, the student should write a comment and suggestion to their peer, while their peer can give his or

her feedback on the comment and suggestion they received. Suggestions and responses to suggestions were open-ended, and there was no limit to the number of characters required to fill in these fields.

Students' projects were evaluated using rubrics in both years (for both the control and experimental groups), and the feedback form was aligned with the elements being evaluated. When creating feedback questions, special care was taken to ensure that students saw what the most important elements were when creating a project.

After the presentation session, students were given three days to complete a feedback form for all members of their group. During those three days, the students had the right to view the work of colleagues from their group, where they could look at the work itself in more detail and adequately answer the questions in the feedback form, giving comments and suggestions to peer colleagues. As previously stated, the peer feedback process is anonymous for the students because they will not know which feedback they received from which colleague. However, for the teaching assistant, the feedback process is not anonymous. The teaching assistant could have an insight into the regularity of giving answers and determine if any of the students did not give their colleagues an answer. In this way, irregularities can be prevented, and, if necessary, the teaching assistant can write to a specific student. In the realization of the described procedure, the authors created a web application that was used for these purposes. As stated earlier, the deadline for posting comments to group members was 3 days. After receiving the comments, the student had a deadline of 5 days to eventually make corrections to the project, correct errors if they were noticed by a peer colleague and improve the program code. After the time had expired, the teaching assistant evaluated the last received version of the project, which was considered to be the final version of the project. The final versions of the websites were evaluated according to the rubrics. Let us emphasize again that the evaluation criteria were the same during the first and second years of research (for the control group and the experimental group of students).

Assessment of the students' project assignment by the teacher

The teaching assistant checks all the students' projects (projects created by the students from the control group and those from the experimental group) and evaluates them according to the table of criteria (see Appendix 1). For both groups, students received a universal table of rubrics, requirements, and criteria, according to which their projects were evaluated.

As can be seen from Table 1 (Appendix 1), each of the sections is marked with a different color. Colors range from lighter to darker, where lighter colors represent simpler project criteria while darker colors represent more advanced project criteria. For each of the categories, we have defined three levels at which the project meets the given criteria: below average, average, and above average. Each of these levels, for each of the criteria, is explained descriptively, along with the number of points that students can achieve for a certain category and a certain level of success in that category. As can be seen, there is a difference of 0.5 between each of the two values on the point scale. In this way, we achieve a more detailed and transparent evaluation process.

Web application for peer review process

To implement peer review, we needed a tool that would divide students into groups and allow them to give specific feedback on each other's work. Although there are applications that enable the division of students into groups and their collaboration, we decided to create our own web application. The application is completely free and can be found at the link: http://evaluacija.xyz/. The main reason for creating an application was a combination of specific requirements for the research. We will start with registration in the application. In the application, it is possible to register as a teacher or as a student. There are different opportunities depending on the chosen role. Naturally, the teacher has a much wider range of powers than the student.

Teacher's role in peer review application

As previously mentioned, registering in the application as a teacher offers a wider range of possibilities and control. If you register as a teacher in the application, your main advantage is that you can create student profiles, divide students into groups, create a survey, add questions, and assign surveys to students who are in the system. Given that the teacher can create student profiles, it significantly facilitates the job of dividing students into groups even without their prior knowledge of the application.

Before the project presentation day, the teacher can very easily create all student profiles (by specifying the students' email addresses), divide them into groups, and be sure that it has provided the necessary prerequisites for peer feedback.

Another important aspect is creating a questionnaire that each of the students will fill out for each of their colleagues in their group. Creating a questionnaire and adding questions is very simple, like in surveys in other similar systems. After creating the questionnaire, it can be assigned to the desired groups of students who need to complete it for each of the members within their group. All students' responses are recorded in the database and can be viewed by the teacher in the user interface of the application. In such a manner, the teacher can follow the interactions and responses of the students, as well as analyze the content of those responses. This type of monitoring is very useful and provides teachers with an extremely broad picture, but on the other hand, it can also be based on the interactions of one specific student or the answers of all students to a specific question.

Observed formative assessment is also the most complex part of the process for the teacher. The teacher must monitor all student interactions and consider the comments and suggestions that the students have received, as well as the reaction of the evaluated students to the comments. Using the example of a four-member group, we will graphically present all interactions that the teacher should monitor. Solid arrows represent giving comments or suggestions on colleagues' work, while dashed arrows represent a feedback response to a comment or suggestion received.

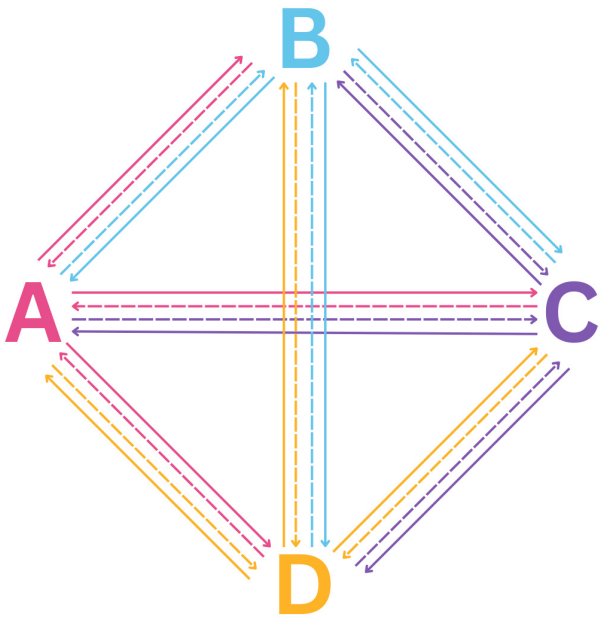

Figure 1. Peer feedback scheme

With a simple calculation, we conclude that in one four-member group, we have 24 interactions. In the concrete example of 13 groups, as many as there were in the experimental group, the teacher needs to check 312 interactions, where each interaction represents the textual feedback or the textual response to the feedback that the student got earlier. This is a very complex process, requiring a lot of energy and time for analysis.

Students' role in peer review application

When a student registers on the web platform, the student uses an email address. After logging in, the student can see all the questionnaires on the page assigned to that email address by the teacher. As the questionnaires are related to peer feedback and each of the students is in a group with their other colleagues, the logged-in student will see more questionnaires to complete. More precisely, the student should write an opinion for the projects of all colleagues from the team and have as many questionnaires as there are members in the group. In our specific case, there were 4 students in each group; therefore, each of the students got 3 projects to evaluate. Questionnaires were coded so that the student knew exactly which project was being evaluated. For example, let there be students A, B, C, and D in one group.

Student A should write feedback for the projects of students B, C, and D. Student A knows exactly which questionnaire is dedicated to student B, which one is to student C, and which one is to student D. After student A gives feedback to colleague B, colleague B receives the feedback in the given form, and from that moment on, they can start considering them. For each of the feedback that they got, student B can give feedback (answer) to the feedback, express an opinion about the feedback received, and forward it to the colleague that they got it from. It can be noticed once again that the teacher who created the questionnaire supervises the entire process of peer feedback, while this process is anonymous for students (students know which other three students write feedback for them because they wrote feedback to them, but they do not know which of this feedback were written by which student).

Results

As already mentioned earlier, rubrics were used for the evaluation of the project by teachers, where five criteria were considered, and for each criterion, three levels were defined depending on the extent to which the students satisfied the given criterion (below average, average, and above average, see Table 1). Since not all criteria were equally important for the quality of the entire project, a scale of the number of points was created for each level within each criterion. Based on all those five criteria, the total number of points for the student project was calculated. Bearing in mind that the number of points, as well as 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 control and experimental groups.

Table 1. *Students' results for every criterion in project assignment*

Criterium	Group	Number of students	Medians	Mean rank	Sum of ranks	Mann-Whitney U test	
						Z	*p* (2-tailed)
Clean code	Experimental	52	1.50	52.80	2745.50	-2.280	0.023
	Control	43	1.50	42.20	1814.50		
Header/ footer, navigation	Experimental	52	3.00	48.82	2538.50	-0.465	0.642
	Control	43	3.00	47.01	2021.50		
Tables, forms, pictures	Experimental	52	3.00	48.80	2537.50	-0.391	0.696
	Control	43	3.00	47.03	2022,50		
Responsive web design	Experimental	52	4.50	53.01	2756.50	-2.032	0.042
	Control	43	3.00	41.94	1803.50		
JavaScript functional part of the web site	Experimental	52	6.50	53.37	2775	-2.114	0.034
	Control	43	5.00	41.51	1785		

The first aspect of the project that was evaluated was "clean code." The maximum number of points that students could score for this criterion was 1.5. Looking at Table 1, as the medians of the given characteristics for both groups are equal to 1.5, we can conclude that more than half of the students in both groups had the maximum number of points. However, the number of students in the experimental group with the maximum number of points in this category is higher, because the distribution of the number of points for "clean code" is statistically significantly different for the students of the experimental group and the control group, in favor of the students of the experimental group (Z=-2.280, p=0.023).

Another aspect that was valued by the teacher (and about which the students were informed) was related to the quality of the students' responses to the requests regarding the header, footer, as well as navigation on the created web page. With the appropriate statistical analysis, it was established that there are no statistically significant differences in the answers of students in the control and experimental groups in the quality of solving this aspect of websites (Z=-0.465, p=0.642). There are no significant differences in the students' results regarding the third criterion, which refers to the choice of tables, forms, and images

for the website, as well as the way in which these elements were implemented on the students' project assignment (Z=-0.391, p=0.696). As the maximum number of points for both criteria are 3 and as the median number of points for both criteria, in both groups of students, equals 3, we can conclude that the students generally responded very well to these requirements, regardless of which group they belonged to.

The next criterion considered during the evaluation of the project assignment by the teacher was related to the responsiveness of the website, which represents one of the two most important segments of the student project assignment.

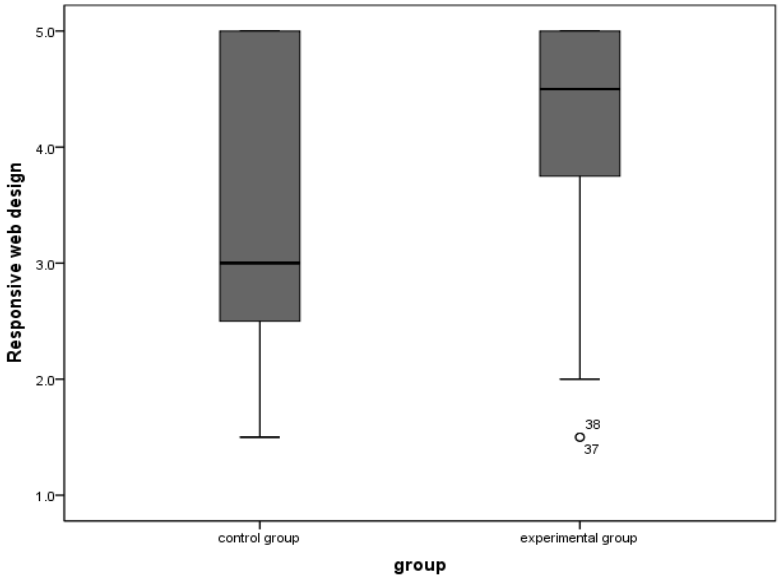

Figure 2. Distribution of points earned by students for web page responsiveness.

The results of the statistical analysis, i.e., the Mann-Whitney test, support the fact that the distribution of the number of points of students in the experimental group and the number of points of students in the control group is statistically significantly different (Z=-2.032, p=0.042). Based on the results presented in Fig.2 and Table 1, the results of the statistical analysis imply that the students of the experimental group responded to a greater extent to the requirements of this extremely important aspect in the creation of a website, i.e., web programming.

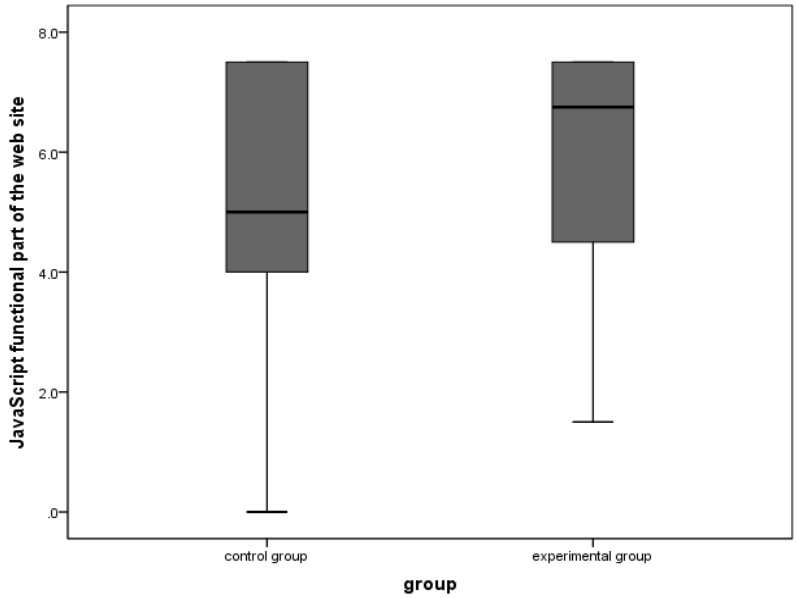

Figure 3. Distribution of points earned by students for the JavaScript functional component of their webpages

The last criterion, and at the same time, the most important one for the successful creation of a website, is the use of JavaScript code in the creation of a website. Out of a total of 20 points provided for the evaluation of the project, 7.5 points could be achieved by the students for JavaScript functionality. Based on the median (which for this feature in the experimental group was 6.5 points and 5 points in the control group), the effects of peer feedback on the success of students can be noticed when it comes to the last criterion (see Fig.3 and Table 1). These differences were confirmed with the Mann-Whitney test, so we can conclude that the differences in students' success in the functionality of the students' project results are statistically significant (Z=-2.114, p=0.034) in favor of the experimental group.

Table 2. *Results of the Mann-Whitney test for total number of points for the project assignment*

Group	Number of students	Medians	Mean rank	Sum of ranks	Test of difference between arithmetic means	
					Z	p (2-tailed)
Experimental	52	18.00	54.30	2823.50	-2.460	0.014
Control	43	15.00	40.38	1736.40		

All the differences in the considered criteria were reflected in the overall result of the project assignment, i.e., the website created by the students on the given topic. Based on the results from Table 2 we can see that students who mutually made formative assessments for the works of their colleagues and had the opportunity to review their work and correct it (after receiving the comments and suggestions of their colleagues), if they think that the acceptance of the comments and working in accordance with those comments could lead to the improvement of their website, achieved better results (the median of the total number of points of the experimental group is 18, while the median of the total number of points of the experimental group is 15 points). This was confirmed by the Mann-Whitney test (Z=-2.460, p=0.014), so we can claim that the peer feedback process of the students' work influenced the students of the experimental group achieved statistically significantly better achievements. This practically represents one of the most significant results of this research.

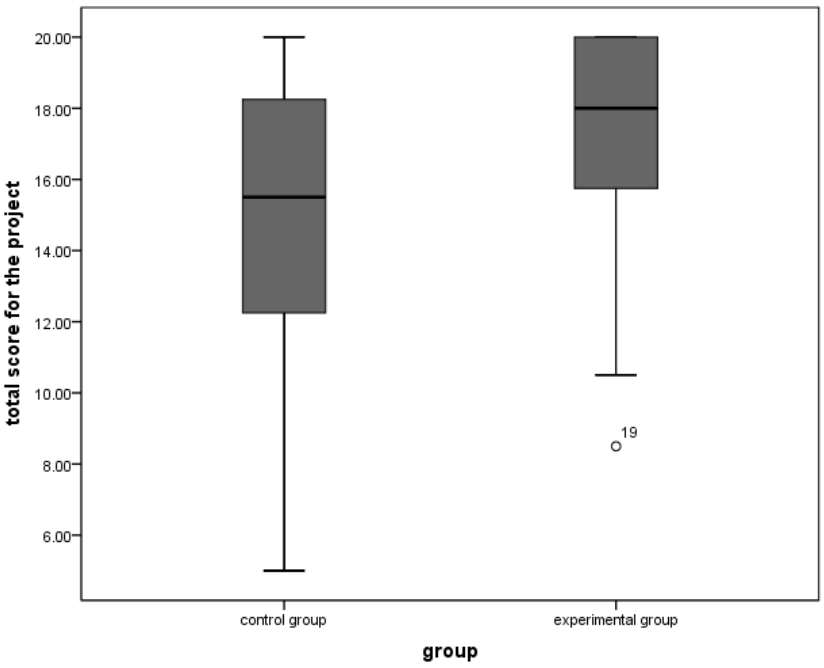

Figure 4. Distribution of total points earned by students for their project assignment

In addition to the analysis of the above-mentioned students' answers, we were particularly interested in whether the students, based on the comments they received from their colleagues, revised their work again. Based on the graph presented in Figure 4, we can conclude that out of 46 surveyed students, only 5 of them did not revise their work, i.e., 89.13% of students have additionally analyzed the product of their project assignment, which speaks in favor of the fact that students took the comments they have

received from their colleagues seriously into consideration. This is also a significant result of this research because it supports the fact that comments and suggestions from peer feedback contribute to higher cognitive levels of learning as well as to the development of critical thinking among students, which is of course one of the goals of higher education in general.

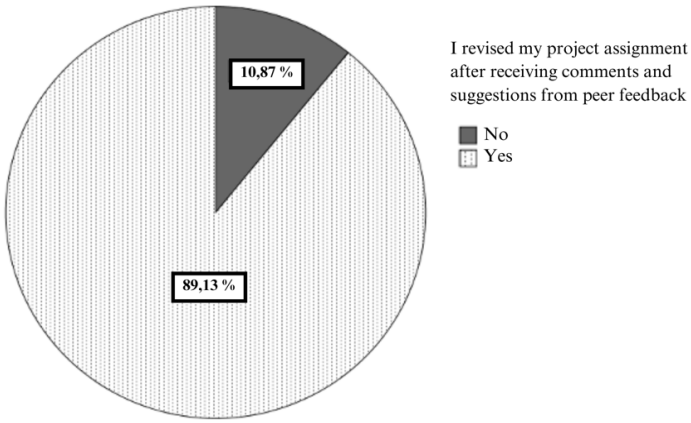

Figure 5. Number of students that revised their project assignment after receiving comments and suggestions from peer feedback

With the second question in the survey, we wanted to determine what percentage of students made certain changes in their work based on the comments and suggestions they received from their colleagues. As many as 36 out of 46 (78.26%) surveyed students made some of the corrections in accordance with what their colleagues advised and suggested. This, of course, speaks in favor of the fact that students, in general, performed a serious evaluation of the given project, which represents another extremely significant result of this methodological approach in the web programming course.

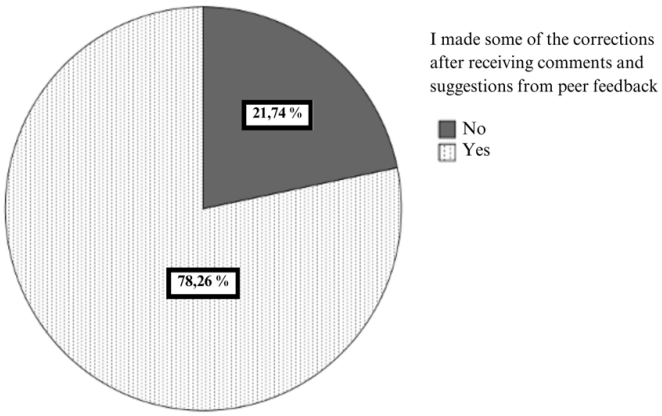

Figure 6. Number of students that made some of the corrections after receiving comments and suggestions from peer feedback.

After the last statement in the questionnaire, we wanted to determine what kind of improvement students made (if they made any changes) after reading and thinking about the peer feedback they received. Therefore, in the questionnaire, we gave the open-ended question to write what kind of changes they made (if they have made any, of course). After analyzing their responses, we categorized them according to the criteria we gave them in the feedback form. We must emphasize that some students made changes regarding more than one criterion, but we also must emphasize that some students commented that they did not agree with some comments and suggestions they received, with the explanation that they did not believe that proposed changes would improve their project assignment.

Table 3. Number of changes that students made according to the comments and suggestions they received from their peer colleagues

Criterion	Number of changes
Changes concerning header and/or footer corrections, images, menus, personal presentation pages, tables, forms, events, and functions.	24
Changes concerning the responsiveness of the site.	12
Changes concerning the content of the page.	9
Changes concerning aesthetic components (choice of colors and text).	18
Changes regarding the visibility and intuitiveness of the site.	7
Changes in JavaScript code.	19

After analyzing the number of changes that students made in Table 3, we can see that the students mostly made changes in their project assignment that they believed they improved. Two-thirds of the students made some changes regarding header and/or footer management, image, menu, personal presentation page, table, form, function, or event. Nineteen students made changes regarding the functionality of the website they created by improving their JavaScript code, which is more than half of the students who made some adjustments. Fifty percent of the students who made some adjustments made their website aesthetically better. One-third of the students who made some changes tried to make the responsiveness of the website better. The changes that refer to the visibility and intuitiveness of the website (7) and its content (9) are present to a lesser extent in students' attempts to improve their project assignments.

Discussion

During the design of the research, we opted for a synchronous approach, establishing a two-way peer-to-peer dialogue involving the exchange of comments and suggestions, as well as responding to received feedback (Adachi, Tai, and Dawson, 2018). The students' analysis of their peers' work, along with a reflective review of their work in line with the received comments and advice for improvement, influenced students' ability to provide their peers with constructive criticism and develop essential cognitive functions such as critical thinking, as it has been linked to the previous research (Wang et al., 2012). Considering that all students fulfilled their obligations regarding providing feedback and responding to it, made efforts to be objective, and made no comments interpreted personally, the significant number of students genuinely considering their peers' advice and suggestions for improving their work indicates that participating in these activities in an online environment contributes to a well-accepted and constructive dialogue (Liu and Carless, 2006). This result aligns with the findings of Falchikov and Goldfinch (2000), who concluded in their meta-analysis that students predominantly provide reasonable and objective comments.

Our results suggest that students thrived in acquiring knowledge and skills related to website creation through the given activities, where they had the opportunity to analyze their peers' works and compare their approaches to solving specific problems with those of their peers (Chang, Tseng and Lou, 2012). The research results indicate that participating in peer assessment through formative evaluation of peers' work (Topping, 2017) supports the learning process and leads to better achievements (Lu and Bol, 2007).

Limitations and recommendations for future research

In this study, we analyze the peer feedback provided by students for their fellow students, aiming to help students achieve better results and critically reflect on their work. During this process, we did not pay attention to the way students were distributed into groups in the context of their achievements, learning styles, and other characteristics. Considering these aspects could be a direction for future, related research.

Conclusions

Based on all the results obtained, we can conclude that using peer feedback gives good results when it comes to integrating the peer feedback process into the project assignment, which refers to creating a website on the given topic. Firstly, we analyzed five criteria to examine the influence of this approach in more detail. Statistically important differences were shown in analyzing the used code "clean"; the

website is responsive, which is of course a very important part of the task, having in mind that we could approach the website from different devices in everyday situations; and of course, the very important part of web programming and website creation, the JavaScript functionality. The differences in students' success in some technical respects, such as headers and footers, navigation, tables, forms, and pictures, between the works of students who didn't have the opportunity to write feedback and read the ones written for their work assignments and the students who did have that kind of opportunity were not significant statistically. Despite that, the differences in clean code, responsiveness of the website, and JavaScript functionality influenced the total score of the students' achievements. This confirms our hypothesis that the web-based peer feedback process contributes to better students' achievements in creating a website compared with the achievements of the students who did not have that opportunity. Additionally, many of the students reviewed their work, and in many cases, they also made some changes that they believed would lead to project improvements. This illustrates that students were aware of the advantages of the web-based peer feedback process for their project assignment, as they had the possibility of improving their assignment. Having all the results in mind, we can conclude that the use of the web-based peer feedback process contributes to better students' achievements while creating their project assignments in a web programming course.

Considering that when creating specific solutions for given problems or requirements from various sectors of society through programming, the way an individual (student) perceives the problem, and its solution may vary to some extent from person to person. Obtaining qualitative peer feedback can indicate to the student that the given problem can be solved in different ways and that various principles and ideas can be considered. Therefore, the possibility for computer science students to write and receive peer feedback should be taken more seriously, and these activities should be practiced more frequently with students during their academic studies.

Conflict of interests

The authors declare no conflict of interest.

Acknowledgments

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Author Contributions

Conceptualization, J.M. and A.M.; methodology, J.M. and A.M.; software, J.M. and A.M; formal analysis, J.M. and A.M.; writing—original draft preparation, J.M. and A.M.; writing—review and editing, J.M. and A.M. All authors have read and agreed to the published version of the manuscript.

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Appendix 1

Rubrics used for the project evaluation

Criteria	Below Average	Average	Above Average	Score
Clean code	The student does not master the basic concepts of code formatting. {0, 0.5}	The student master's the basic concepts of code formatting but does not divide the code into functional units. {1}	Well formatted and organized code. {1.5}	
Header/footer, navigation	Header/footer and navigation do not exist or exists, but they are not functional. {0, 0.5, 1}	Header/footer and navigation exist but their functionality is partial. {1.5, 2}	The header/footer and navigation are fully functional and meet the needs of the website. {2.5, 3}	
Tables, forms, pictures	Tables, forms, and images do not exist or exist, but they are not functional. {0, 0.5, 1}	Tables, forms, and images exist, but they are not fully functional or the data in them is not transparent or well organized. {1.5, 2}	Tables, forms, and images are fully functional, data is well organized and transparent. {2.5, 3}	
Responsive web design	The website adapts to only one type of device (mobile only, desktop only or tablet only). {0, 0.5, 1, 1.5}	Most elements adapt well to different types of devices. {2, 2.5, 3, 3.5}	All elements adapt well to all types of devices. The elements are well laid out on the page. {4, 4.5, 5}	
JavaScript functional part of the web site	Functional units on the page do not exist or exist but they are developed at a low level. {0, 0.5, 1, 1.5, 2, 2.5, 3}	Functional units on the page exist and are written correctly. However, not all parts of the application are covered by these functionalities. {3.5, 4, 4.5, 5, 5.5}	All pages are fully covered with correctly coded functionalities. {6, 6.5, 7, 7.5}	

Appendix 2

Questionnaire for students' peer feedback

Question	Comment / Suggestion (provided by a colleague who evaluates the project)	Response to a comment / suggestion (provided by a colleague whose project is the subject of evaluation)
Does the created website correspond to the set requirements of the project (contain header and/or footer, image, menu, personal presentation page, table, form, function, and events)?		
Is the site responsive? Does the page design adapt to the device on which the website is viewed?		
Does the content of the site correspond to the given topic?		
Is the website visually responsive? Is the color selection harmonious and the text legible?		
Is the arrangement of elements on the page clear and intuitive? Does everything on the page work easily and is intuitive?		
Would you add any segment to improve the quality of the website?		
Opinion about the colleague's presentation (pace of the presentation, emphasis on the most important parts, precision, and systematic presentation...).		

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The Effect of Citizen Science Project Learning Model on Students' Critical and Creative Thinking Skills

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Abstract: Critical and creative thinking skills are essential in 21st-century education, but conventional learning approaches are still less effective in developing these skills. This study aims to analyze the influence of the Citizen Science Project learning model on the critical and creative thinking skills of high school students in Indonesia. The research method used experiments with post-test control groups, involving 70 students divided into experimental and control groups (35 students each). Instruments in the form of essay questions were used to measure students' critical and creative thinking skills, while data were analyzed using quantitative descriptive analysis and inferential statistics using the MANOVA test. The results showed that the Citizen Science Project model significantly improved students' critical and creative thinking skills compared to conventional learning ($p < 0.05$). This improvement demonstrates the effectiveness of the model in facilitating high-level thinking skills. These findings indicate that the Citizen Science Project can be an innovative strategy in learning to improve 21st-century skills. Therefore, this model is recommended to be applied in Education.

Keywords: *citizen science project, critical thinking skills, creative thinking skills, student.*

Introduction

The quality of education in Indonesia still faces significant challenges at the international level. Based on the UNESCO report, Indonesia ranks 64th out of 120 countries in terms of quality of education. In addition, the education development index 2015 shows that Indonesia ranks 57th out of 115 countries. The latest data from the Programme for International Student Assessment (PISA) in 2022 reveals that the quality of education in Indonesia is still relatively low, ranking 68th out of 81 countries. These findings reflect the low ability of students to think critically, think creatively, interpret information, and solve problems in various aspects of life. This low ranking also indicates a decline in academic achievement globally (learning loss), which requires serious attention from various parties.

One of the main causes of the low quality of education in Indonesia is the dominance of a learning system that is still teacher-centered, memorization-oriented, and evaluation that emphasizes low-level cognitive aspects. This is in contrast to countries such as Finland, Singapore, and Japan that have adopted inquiry-based, project-based, and collaborative learning approaches. The education system in Indonesia still faces challenges in developing learning strategies that are oriented towards strengthening higher-order thinking skills (HOTS).

The development of HOTS-oriented learning is one of the programs developed by the Ministry of Education as an effort to improve the quality of learning and the quality of graduates (Adnan et al., 2014; Maryani et al., 2021). In addition, the HOTS capability is also applied to catch up with Indonesia's ranking in PISA and Trends in International Mathematics and Science Study (TIMSS) compared to other countries (Rindermann and Baumeister, 2015; Adnan and Bahri, 2018). Countries that excel in implementing HOTS

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learning have strategic approaches to overcoming education problems. For example, Finland relies on personalized learning and a flexible curriculum by giving teachers broad autonomy; Singapore emphasizes a competency-based curriculum focusing on problem-solving and logical reasoning; and Japan strengthens a collaborative and reflective learning culture through lesson studies and classroom discussions. These approaches have proven to be effective in improving students' quality of education and higher thinking skills.

HOTS abilities are closely related to critical and creative thinking competencies that are key needs in 21st-century learning (Eskiyurt and Özkan, 2024; Hews et al., 2023; Ghanizadeh et al., 2024; Hikamah et al., 2021). Critical thinking skills can be trained through systematic and specific analysis and identification of problems, as well as designing strategies as solutions to problems faced in the surrounding environment (Almunawarah et al., 2023; Fabian et al., 2024; Mahanal et al., 2019). Meanwhile, creative thinking skills can be developed through efforts to find innovative solutions, analyze problems from various perspectives, and generate unique ideas (out of the box) that are integral parts of advanced thinking skills (Rohman et al., 2024; Adnan et al., 2021; Nurjanah et al., 2024; Juniati and Budayasa, 2024).

The main problem faced by education in Indonesia is students' low critical and creative thinking skills. This lack of high-level thinking skills suggests that many students still have difficulty analyzing information, solving complex problems, and coming up with innovative ideas. Traditional learning systems that focus on memorization and passive mastery of material are factors that slow down the development of students' thinking skills (Bremner et al., 2023; Woods and Copur-Gencturk, 2024). This condition is a challenge for educators in providing learning by the demands of the 21st century. One approach that has the potential to be an effective solution is the Citizen Science Project (CSP) learning model.

Theoretically, CSP is rooted in constructivist (Vygotsky, 1978) and experiential learning (Kolb, 1984) approaches that emphasize that knowledge is built through direct experience, social interaction, and reflection. In CSP, students are actively involved in real scientific processes such as data collection, field observation, and results analysis. These activities encourage the development of high-level thinking skills such as analysis, evaluation, critical thinking, and creation (Bloom's Revised Taxonomy). A number of studies also support the effectiveness of CSP in increasing HOTS. Bonney et al. (2009) show that participation in citizen science projects can improve scientific literacy and critical thinking skills. Ballard et al. (2017) and Stein et al. (2023) found that involvement in CSP helps students develop analytical and evidence-based problem-solving skills. Zoellick et al. (2012), Sanabria et al. (2022), Gray et al. (2012), and Edson et al. (2024) affirm that CSP facilitates reflective and systemic thinking because students are directly involved in real issues. In addition, Mitchell et al. (2017) and Jadallah and Wise (2023) also show that CSP supports scientific inquiry, data analysis, and argumentation skills. Thus, in theory and practice, CSP has proven to be effective in developing HOTS through authentic, contextual, and socially meaningful learning.

When compared to other learning models, CSP has its own uniqueness. Problem-based Based Learning (PBL) focuses on solving hypothetical problems in the classroom, and inquiry-based Based Learning (IBL) emphasizes the process of scientific inquiry, while CSP combines both approaches in a real-world context. Similarly, compared to Project Based Learning (PJBL), which focuses on the design and implementation of projects by students, CSP has additional depth in involvement in authentic scientific processes and real contributions to producing knowledge or solutions used by scientific communities or institutions. If PJBL student projects tend to be simulative or internal in the school environment, then in CSP, the students' work results are real, documented, and can be used by the public or stakeholders. Therefore, CSP is relevant in strengthening HOTS and plays a strategic role in shaping students' civic awareness and social responsibility. Integrating scientific learning, social engagement, and tangible contributions makes CSP a transformative learning model in the 21st-century education era.

Although previous research has shown that CSP is able to improve scientific literacy and critical thinking skills, most of the studies still focus on overseas contexts, especially in countries with well-established education systems. In addition, most of the research emphasizes the participatory aspects and general impacts on science literacy but has not specifically examined how CSP contributes to the measurable development of HOTS in formal education, particularly in Indonesia. These limitations create a gap in understanding the effectiveness of CSP as an innovative learning strategy in the local environment that is still dominated by memorization approaches and teacher-centered learning. Therefore, this study aims to fill this gap by empirically examining the influence of the implementation of CSP on the development of student HOTS in Indonesia and adapting it to the characteristics of the national curriculum and the dynamics of learning in the classroom.

The Citizen Science Project learning model consists of seven stages: project problem orientation, project planning, timeline creation, project implementation, project monitoring, project assessment, and project evaluation. These stages were developed by adapting project-based learning models but have important differences. In CSP, there is community involvement in data collection, expert involvement in the mentoring process, and integration of web-based learning technology equipped with learning resources and practical guidance for project implementation. Through these stages, researchers will observe their impact on improving students' critical and creative thinking skills. The results of this research are expected to be a foundation for policy makers, educators, and other stakeholders in designing more effective learning strategies to improve the quality of education in Indonesia.

Materials and Methods

Population and Sample

The population in this study is all students of class X of SMAN 9 Makassar for the 2024/2025 school year. The research sample consisted of two classes that were selected using the intact group sampling technique, which is the selection of groups that have formed naturally without changes in composition. The sample totaled 70 students, with details of 35 students as the experimental group and 35 students as the control group.

Both classes have similar initial characteristics based on the previous semester's report card scores and come from relatively homogeneous socioeconomic backgrounds. There was no pre-test because this study used a post-test only control group design, but the class selection considered the equivalence of the initial academic level to minimize bias.

Research Design and Procedure

This study uses a post-test-only control group design. The experimental group was given the Citizen Science Project (CSP) learning model, while the control group used the Student Team Achievement Division (STAD) model.

The implementation of the intervention lasted for three months**,** with 12 meetings in each class for two hours of lessons (2 × 45 minutes) per meeting. In the experimental class, the CSP model is implemented through seven main stages: (1) Project problem orientation, students recognize environmental problems around, especially those related to biodiversity. (2) Creation of a project plan, collaborating with group members to formulate project objectives and methods. (3) making a timeline, adjusting the activity schedule to suit the time and existing resource limitations. (4) Project implementation is done through field observation, recording, and visual documentation. Students analyze the data obtained, draw conclusions, and discuss collaboratively. (5) Monitor the project, report progress and obstacles faced, discuss in groups to find solutions, and reflect on the process that has been passed. (6) Project assessment, presenting project results. (7) evaluate the project, write personal and group reflections on the project experience, discuss the learnings gained, and provide project input for future improvement

The researcher served directly as the teacher in both classes: the experimental class, which implemented the Citizen Science Project (CSP) model, and the control class, which used the Student Teams Achievement Division (STAD) model. This ensured consistent and procedural implementation of both learning models as designed.

Research Instruments

The instruments used to measure students' critical thinking abilities are essay tests that refer to the FRISCO model developed by Ennis et al. (2005), Ennis and Millman (2008), and Ennis (2011), with indicators of focus, reason, conclusion, situation, clarity, and review. Meanwhile, creative thinking ability was measured using an essay test based on indicators developed by Guilford (1950, 1967, 1968), with indicators of fluency, flexibility, originality, and detail.

All questions are adjusted to the context of biology learning, especially the biodiversity material. The instrument has gone through an expert validation process using Aiken's V, with an average V value of ≥ 0.87, indicating high content validity. The reliability of the instrument was tested using Cronbach's Alpha, with $\alpha = 0.81$ for the critical thinking test and $\alpha = 0.85$ for the creative thinking test, indicating high reliability.

Data Analysis

The data from the post-test results was analyzed through several stages. First, prerequisite tests are carried out as normality and homogeneity tests to ensure the data meets inferential statistical assumptions. Furthermore, to test the research hypothesis, an analysis was carried out using Multivariate Analysis of Variance (MANOVA) by looking at the values of Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. The Pillai's Trace value is a positive value with an increased value statistic indicating an effect that contributes more to the model, and Wilks' Lambda is a positive statistical value that ranges from 0 to 1, with a smaller value indicating a more contributing effect to the model. Hotelling's Trace with an increased positive value shows a more contribution effect to the model, and Roy's Largest Root gives the same value as Hotelling's Trace; there is a strong correlation between dependent variables (Sarwono, 2017). In addition to MANOVA, an independent sample t-test was also carried out to compare the average scores between the experimental and control groups. Hypothesis testing was carried out using SPSS 24 software for Windows, with the basis for decision-making that if the significance value (2-tailed) < 0.05, then H0 is rejected and H1 is accepted, which means that there is a significant difference between the experimental group and the control group in improving critical and creative thinking skills, and if the significance value (2-tailed) > 0.05, then H0 is accepted and H1 is rejected. which means there is no significant difference between the two groups (Herzog et al., 2019). With this method, the study aims to prove that the Citizen Science Project learning model has a more significant influence than the STAD model in improving high school students' critical and creative thinking skills.

Results

Critical and Creative

Based on Table 1, it can be observed that the average value of the critical thinking and creative ability class of the experimental class was higher than that of the control class. The average critical thinking ability of the experimental class was 69.89, while the control class was 56.86. Therefore, the difference between the two is 13.03. The average creative thinking ability of the experimental class was 70.80, while the control class was 54.00, so the difference between the two was 16.8. The highest score of critical thinking in the experimental class was 98.00, and the highest score of creative thinking was 91.00, while in the control class, the highest score of critical thinking was 78.00, and the highest score of creative thinking was 72.00. Furthermore, for the standard deviation of the experimental class, 12.98 is critical thinking, and 10.38 is creative thinking. The standard deviation of the control class was 11.19 for critical thinking and 8.39 for creative thinking.

Table 1. *Critical and creative descriptive statistics of students in experimental and control classes*

No.	Statistics	Critical Thinking		Creative Thinking	
		Experiment Class	Control Class	Experiment Class	Control Class
1	Sample Quantity	35	35	35	35
2	Average	69.89	56.86	70.80	54.00
3	Highest Score	98.00	78.00	91.00	72.00
4	Lowest Score	48.00	40.00	44.00	41.00
5	Standard deviation	12.98	11.19	10.38	8.39

This quite striking difference in average scores shows statistical significance and has practical implications in the context of learning. According to Cohen (1988), a difference of more than 0.8 standard deviations can be categorized as a significant effect in education. With a score difference of more than 13 points (for critical thinking) and 16 points (for creative thinking), these results show that the use of the Citizen Science Project (CSP) learning model provides a significant and substantial improvement in students' cognitive achievement.

The value of critical and creative thinking skills is then grouped by category based on the students' post-test results. Table 2 shows the frequency distribution and percentage of critical and creative thinking skills in both the control class and the experimental class.

Table 2. *Distribution of frequency and percentage of students' critical and creative thinking skills in the classroom Experimental and controls*

No.	Category	Critical Thinking				Creative Thinking			
		Experiment Class		Control Class		Experiment Class		Control Class	
		F	%	F	%	F	%	F	%
1	Very High 81 ≤ x ≤ 100	9	25.71	0	0	7	20.00	0	0
2	Good 61 ≤ X < 80	17	48.57	11	31.43	22	62.86	9	25.71
3	Simply 41 ≤ X < 60	9	25.71	23	65.71	6	17.14	26	74.29
4	Less 21 ≤ X < 40	0	0	1	2.86	0	0	0	0
5	Very low X < 20	0	0	0	0	0	0	0	0

The results of critical and creative thinking skills obtained by students in Table 2 interpret that the critical thinking skills in the experimental class were 9 (25.71%) students who obtained very high results, there were 17 (48.57%) classified as good, and there were 9 (25.71%) classified as adequate. Meanwhile, 11 (31.43%) were classified as good, 23 (65.71%) were classified as adequate, and 1 (2.86%) was classified as lacking. The interpretation of creative thinking skills in the experimental class was 7 (20.00%) classified as very high, there were 22 (62.86%) classified as good, and there were 6 (17.14%) classified as sufficient. While 9 (62.86%) of the control class were classified as good and 26 (74.29%) were classified as adequate, From the data, it can be seen that students in the experimental class tend to have a higher distribution in the "Very High" and "Good" categories than the control class. This reflects that the Citizen Science Project's learning model is more successful in improving students' high-level thinking skills.

Normality Test

Based on the Kolmogorov-Smirnov normality test results in Table 3, the significance value (Sig.) is greater than 0.05, meaning the data is usually distributed. In addition, the homogeneity test was carried out using the Levene test and the Kovarian Box matrix equivalence test. The results of the Levene test showed that the Sig. value for critical thinking skills was 0.351 and for creative thinking skills was 0.312, both of which were greater than 0.05, so the data were declared homogeneous. The use of the Box covariance matrix equivalence test yielded a Sig. value of 0.263 also showed that the data were homogeneous

Table 3. *Normality Results*

	Learning Model	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig. > 0.05
Critical Thinking	Model Citizen Science Project	.096	35	.200
	STAD model	.145	35	.060
Creative Thinking	Model Citizen Science Project	.074	35	.200
	STAD model	.134	35	.113

Hypothesis Test

The prerequisite test for the MANOVA analysis has been completed, so the results of the MANOVA test can be used for hypothesis testing. Based on the results of Table 4, it shows four significance tests for each of the model's effects of the Pillar Trace value of 0.453, which means that it has a more contribution effect on the model, Wilks' Lambda value of 0.547, which gives a more contribution effect to the Hotelling's Trace value model of 0.830 equal to the value of Roy's Largest Root which means that there is a strong correlation between the dependent variables and for the F coefficient is 27.792 with a Sig. 0.00, and the Partial Eta Squared is 0.453, which shows that the treatment explains 45.3% of the variance in students' critical and creative thinking abilities. This shows a difference in the ability to think critically and creatively between students who are taught with the Citizen Science Project and STAD learning models.

Table 4. *MANOVA test analysis results*

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.981	1691.644	2.000	67.000	.000	.981
	Wilks' Lambda	.019	1691.644	2.000	67.000	.000	.981
	Hotelling's Trace	50.497	1691.644	2.000	67.000	.000	.981
	Roy's Largest Root	50.497	1691.644	2.000	67.000	.000	.981
Treatment	Pillai's Trace	.453	27.792	2.000	67.000	.000	.453
	Wilks' Lambda	.547	27.792	2.000	67.000	.000	.453
	Hotelling's Trace	.830	27.792	2.000	67.000	.000	.453
	Roy's Largest Root	.830	27.792	2.000	67.000	.000	.453

Based on the findings of the analysis in Table 5. The results of the ability to think critically and creatively have a partially significant impact. The results of the Tests of Between-Subject Effects study showed in detail that the value of F was 20.184 with a Sig. of 0.00, which was less than 0.05. This shows that the learning model given influences critical thinking skills. In addition, an F value of 55.336 with a Sig. of 0.00, less than 0.05, and Partial Eta Squared of 0.229 (22.9%) and creative thinking of 0.449 (44.9%). Thus, it was revealed by the analysis of Tests of Between-Subject Effects that the learning model provided influenced the ability to think creatively. The influence of the CSP model on creative thinking skills is more significant than on critical thinking skills. This is most likely related to the natural characteristics of the Citizen Science Project, which is 1. to encourage open exploration and diverse problem-solving approaches, 2. Involve students in real projects that do not have one definitive answer, 3. provides ample space for students to innovate and express ideas in an original way.

The nature of community-based scientific projects that demand creativity and originality in developing solutions allows students to show divergent thinking, i.e., the ability to think creatively in various directions. In contrast, more structured critical thinking is still improving, but not as high as creative thinking skills because it may require additional instructional reinforcement

Table 5. *Results of test analysis of between-subjects effects*

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Berpikir_kritis	2970.514a	1	2970.514	20.184	.000	.229
	Berpikir_kreatif	4939.200b	1	4939.200	55.336	.000	.449
Intercept	Berpikir_kritis	281115.657	1	281115.657	1910.091	.000	.966
	Berpikir_kreatif	272563.200	1	272563.200	3053.628	.000	.978
Treatment	Berpikir_kritis	2970.514	1	2970.514	20.184	.000	.229
	Berpikir_kreatif	4939.200	1	4939.200	55.336	.000	.449
Error	Berpikir_kritis	10007.829	68	147.174			
	Berpikir_kreatif	6069.600	68	89.259			
Total	Berpikir_kritis	294094.000	70				
	Berpikir_kreatif	283572.000	70				
Corrected Total	Berpikir_kritis	12978.343	69				
	Berpikir_kreatif	11008.800	69				

The analysis results in Table 6 show that the CSP model significantly increases critical thinking scores by 13,029 points and creative thinking by 16,800 points (Sig. = 0.000). This difference is not only statistically significant but also practical in the context of education, as an increase above 10 points on a scale of 100 can have a tangible impact on students' achievement and high-level thinking readiness. Overall, these results confirm that using the Citizen Science Project learning model is significantly more effective in improving creative thinking skills while still making a meaningful contribution to improving students' critical thinking skills.

Tablel 6. *Parameter estimates*

Dependent Variable	Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
						Lower Bound	Upper Bound	
Berpikir Kritis	Intercept	56.857	2.051	27.727	.000	52.765	60.949	.919
	CSP	13.029	2.900	4.493	.000	7.242	18.815	.229
	STAD	0[a]	.	.	.	.	.	.
Berpikir Kreatif	Intercept	54.000	1.597	33.814	.000	50.813	57.187	.944
	CSP	16.800	2.258	7.439	.000	12.293	21.307	.449
	STAD	0[a]	.	.	.	.	.	.

Discussions

The study results show that the Citizen Science Project (CSP) model can improve students' critical and creative thinking skills. Students involved in this project are more active in collecting data, analyzing information, and solving problems. This is in line with Adnan et al. (2024), Adnan et al. (2025) who stated that CSP divides the learning process into seven main steps: (1) project problem orientation, (2) project plan creation, (3) timeline creation, (4) project implementation, (5) project monitoring, (6) project assessment, and (7) project evaluation. Following these steps makes the learning environment more engaging, and students are more motivated to solve problems. They learn theory and apply fundamental skills that will be useful in the future, improving their critical and creative thinking abilities.

Critical thinking skills are the primary foundation that supports the development of high-level thinking skills, which include analytical and evaluation skills (Gavronskaya et al., 2022; Malik and Ubaidillah, 2020; Molokhina et al., 2021). These results are reflected in the CSP syntax, particularly at the stage of problem orientation, project planning, and timeline development. Learning strategies such as problem-based and project-based learning are effective in developing students' critical thinking (Sahira et al., 2023; Na et al., 2022; Sahira, 2023). This strategy encourages students to become critical thinkers (Eskiyurt and Özkan, 2024; Ma, 2023), which is seen as students drawing up project plans based on real problems. Students are given the role of researching, evaluating, and processing information from various sources to activate critical thinking skills (Angelelli et al., 2023; Jiang, 2022; Belousova, 2020). The syntax of project implementation, project monitoring, project assessment, and evaluation in CSP reflects these activities in real terms. Therefore, CSP is relevant and appropriately used to improve students' critical thinking skills because it makes critical thinking skills the core of the overall project process.

Creative thinking skills involve the merging of divergent and logical thinking. Divergent thinking is used to explore various ideas and solutions, while logical thinking is needed to evaluate and develop such solutions concretely (Lee et al., 2020; Ristic et al., 2023; Akhmetsapa et al., 2024; Waskito et al., 2024). This can be seen in the CSP syntax, especially at problem orientation, project planning, timeline creation, and project implementation. Students are encouraged to generate original ideas, formulate creative questions, and develop innovative solutions (Yildiz and Guler, 2021; Hews et al., 2023; Zdanevych et al., 2020). During project monitoring, assessment, and evaluation, students are trained to refine their solutions, reinforce originality, and creatively evaluate results. CSP facilitates exploration, innovation, and adaptation in the face of challenges, making it an effective model for developing creative thinking skills.

Table 1 shows that CSP significantly impacts critical and creative thinking skills more than the STAD learning model. This is due to the active and contextual learning approach that CSP offers. Each stage in the CSP syntax systematically encourages the development of students' thinking skills, from problem orientation that builds connections to real issues to in-depth project reflection. Table 2 corroborates these findings by showing that most students in the experimental class were in the good and excellent categories, which is inversely proportional to the distribution in the control class. This suggests that statistically significant differences in scores also reflect a practically meaningful effect in the context of learning. For example, the average critical thinking score of the experimental group was 69.89 compared to 56.86 in the control group, indicating that CSP was not only statistically superior but also had a real impact in encouraging the improvement of the quality of students' thinking in the classroom.

Nonetheless, it is necessary to explain further how the CSP mechanism is specifically superior to STAD. STADs rely more on cooperative learning in fixed groups and merit-based task sharing, while CSPs provide greater exploratory freedom and genuine engagement with communities and authentic issues. The involvement of experts and digital platforms adds value to CSPs, which is not found in the STAD approach. However, the effectiveness of CSP can also be influenced by several external factors, such as teacher support, student motivation, and the availability of digital resources. Therefore, CSP's advantage in improving HOTS comes from the model itself and its supporting ecosystem.

The MANOVA analysis and the Test of Between-Subjects Effects test showed that CSP significantly influenced both thinking skills. However, the Partial Eta Squared value for creative thinking (0.449) is higher than critical thinking (0.229), which means that CSP has a more significant influence on the creative aspect. This can be explained through the characteristics of CSP, which are based on exploration, idea submission, open collaboration, and interaction with real contexts that further challenge students' creativity. A flexible approach to problem-solving and community involvement in projects enriches students' perspectives, encouraging them to develop new and original solutions.

Integrating CSP with digital technology through the website platform also strengthens its effectiveness. Students can upload data, discuss with experts and the community, and access online learning resources. This supports a collaborative, open, and continuous learning process. The website also allows the community to be actively involved, enriching the student learning experience and encouraging the creation of a participatory learning ecosystem.

However, the implementation of CSP also has its challenges. This model is optimal for students with good independent learning and collaboration skills. Students who are still familiar with passive learning or have limitations in managing projects may have difficulty following the CSP syntax. In addition, the success of the implementation is highly dependent on the competence of teachers as active facilitators, as well as the readiness of the technological infrastructure. Technical obstacles such as limited devices, uneven internet access, and limited time in the curriculum are obstacles in themselves. Resistance from teachers and students can also arise if they are not familiar with the project-based approach and community involvement.

In addition, there are still limitations in the literature that reviews the failure or ineffectiveness of CSP. Previous studies have tended to emphasize the success of CSP, while studies showing that CSP does not have a significant impact on Higher Order Thinking Skills (HOTS) are still very limited. Therefore, the findings in this study can be an important contribution to strengthening the empirical evidence regarding the effectiveness of CSP. However, it takes follow-up studies with different contexts, populations, and subject areas to test the consistency of these findings.

The practical implications of this study are important to elaborate further. If CSP proves effective, teachers can integrate this model into the curriculum through subjects such as science, social studies, or Language, as long as the learning topic contains elements of real problems that can be researched and solved collaboratively. This model can also be adapted to cross-subject learning through thematic projects. For schools with large student numbers, CSP can be implemented as small group work to be more effective. Teacher training, time flexibility, and technological support are the keys to its successful implementation. Thus, CSP can be an adaptive, collaborative, and contextual learning approach in developing students' HOTS at various levels and conditions of educational units.

Conclusions

The Citizen Science Project (CSP) model has proven effective in improving students' critical and creative thinking skills. The analysis results show that CSP's influence is more substantial on creative thinking skills, which can be seen from the higher Partial Eta Squared value compared to the critical thinking aspect. CSP's syntax emphasizing exploration, collaboration, and real-world problem-solving provides space for students to actively engage in meaningful learning processes. This model can be applied flexibly across a range of subjects, not limited to science and STEM, as long as the learning topic is relevant to the authentic issue for which the project can be used. Teachers play an important role as facilitators, and technology support is the main factor in implementing CSP in the classroom.

For wider implementation, education policies that support the integration of CSP in the curriculum are needed, including teacher training, flexible time allocation, and adequate digital infrastructure. Further research is recommended to examine the long-term impact of CSP implementation and explore other

variables such as gender differences, student learning styles, or school characteristics. Thus, the effectiveness of CSP can be tested in various contexts and produce learning models that are more inclusive and adaptive to the needs of learners in the 21st-century learning era.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualisation: Adnan, Sitti Saenab, and Rahmatullah; Data curation: Adnan, Rifka Almunawarah, and Sahla Sahira; Formal analysis: Adnan, Rahmatullah, and Rifka Almunawarah; Funding acquisition: Adnan; Investigation: Adnan, Sitti Saenab, Rahmatullah, Rifka Almunawarah, and Sahla Sahira; Methodology: Adnan, Sitti Saenab, and Rifka Almunawarah; Project administration: Adnan; Resources: Adnan and Sitti Saenab; Software: Adnan; Supervision: Adnan; Validation: Adnan and Rahmatullah; Visualization: Adnan and Rifka Almunawarah; Writing – original draft: Adnan and Sitti Saenab; Writing – review and editing: Adnan, Rahmatullah, Sitti Saenab, and Rifka Almunawarah. All authors have read and approved the final version of the manuscript for submission.

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The Correlation Between Academic Media Multitasking and Achievement-a Meta-Analysis

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Abstract: Academic media multitasking specifically refers to the phenomenon where students or academics divide their attention between learning-related activities, such as studying or reading scholarly material, and non-learning activities like texting friends, checking social media, or browsing unrelated websites. Studies confirm a negative correlation between media multitasking and academic achievement, with some reporting small to moderate effects or no correlation at all. This topic is particularly important today due to the pervasive use of media among younger generations and its impact on attention, focus, academic performance, and cognitive load. This meta-analysis aimed to quantitatively integrate individual correlational studies and draw general conclusions about the relationship between academic media multitasking and academic achievement. The sample comprised studies published in English scientific journals from 2010 to the present, with methodological characteristics matching the context of this analysis. A total of 11 studies were included in the final analysis. Correlation coefficients were used as a measure of effect size, with both fixed and random effects models applied to calculate the overall measure of effect size. The quality of the included studies was assessed, and potential publication bias was examined using a symmetry graph and Trim and Fill analysis. The results confirmed a low-intensity negative correlation between digital multitasking and academic achievement with a weighted average correlation coefficient of r=−0.252 (fixed effects model) and r=−0.246 (random effects model) and high heterogeneity (I^2 = 93.98%) among the studies, suggesting variability in the findings. The present meta-analysis also revealed high heterogeneity among the studies, suggesting variability in the findings. This heterogeneity opens avenues for exploring potential mediating relationships or covariates that impact why students engage in digital multitasking.

Keywords: *academic media multitasking, academic achievement, GPA, media use, meta-analysis.*

Introduction

The digital environment provides opportunities for communicating, accessing, creating, and sharing an abundance of information effortlessly, quickly, and almost ubiquitously. The consequence of having so many choices is divided attention: an individual constantly switches attention between different types of information while performing various tasks – in other words, they perform multiple tasks simultaneously, or multitask. Although the term "multitasking" suggests that a person is doing multiple things at once, what actually happens is a change of activity (Wagner, 2018). Therefore, multitasking in the true sense refers to the ability to quickly switch attention from one activity to another (Kirschner and De Bruyckere, 2017). In psychological literature, the term media multitasking refers to behaviors such as using multiple devices like smartphones, computers, and smart TVs simultaneously, managing numerous active applications and constant notifications that redirect attention between tasks (Baumgartner et al., 2014).

Current research predominantly investigates the adverse impacts of multitasking across three primary domains: cognition and academic performance, health outcomes, and interpersonal relationships (Za-

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manzadeh and Rice, 2021). Multitasking in educational context, or academic media multitasking (Merrill, 2018; van der Schuur et al., 2020) is engaging with another media source or media technology while primarily working on academic coursework, such as checking social media while doing homework (Yeykelis et al., 2014). Multitasking in interpersonal context may be when we use mobile phone while we talk to our partner. The results show that even the passive presence of a phone can reduce the sense of closeness, trust, and empathy between conversation participants (Przybylski and Weinstein, 2013). In domen of health distractions such as mobile or other media can lead to increased food intake, poor dietary choices, and a higher risk of obesity (Robinson and Matheson, 2015). The focus of our study is on academic media multitasking.

Adolescence and early adulthood is a period when digital media are frequently used during academic activities (Carrier et al., 2015; Junco and Cotten, 2012; Wallis, 2010), therefore, our study includes research focused on populations of high school students and college students. Young people find it difficult to distance themselves from their phones, which is supported by the fact that the smartphone is perceived as an "extension of the body" with a strong sense of emotional attachment (Gertz et al., 2021). The phone is always "at hand" during young people's daily activities, including academic ones. Students often justify device use for course-related tasks, while significant time is spent on non-course-related activities, impacting focus and potentially leading to lower academic performance (Kraushaar and Novak 2010; Rosen et al., 2013). The use of digital media is how adolescents and young adults mostly spend their time, on average more than 7.5 hours a day – which is almost equivalent to the length of a typical workday (Rideout et al., 2010). Students and young adults increase their digital media absorption by using two or more media simultaneously through multitasking, experiencing 10h and 45 minutes of media content within their 7.5 hours per day. This behavior also manifests in educational institutions, where the use of digital media is largely uncontrolled and unregulated. If students do not invest enough time in completing academic tasks, they will not fully utilize their potential (Fox et al., 2009). Researchers who have examined the relationship between media use during academic activities and academic achievement assume that media use during academic activities can lead to negative consequences for young people's academic performance (Bellur et al., 2015; Fox et al., 2009; Karpinski et al., 2013; Kokoç, 2021; Kostić and Ranđelović, 2022). Several cognitive learning theories assume that using multiple streams of information reduces information processing as a result of the limited cognitive capacity of humans (Salvucci and Taatgen, 2010; Junco and Cotten, 2011). Cognitive theories related to information processing (Mayer, 1998) and multimedia learning (Mayer and Moreno, 2003) highlight that "meaningful learning" happens when individuals are actively engaged with information, concentrate on new inputs, and systematically integrate this new information into their pre-existing knowledge structures. These theories indicate that multitasking, or frequently switching between tasks, causes individuals to be only partially engaged with each task, leading to decreased attention and poorer learning and performance outcomes (Kraushaar and Novak, 2010). The cognitive control deficit resulting from frequent digital media multitasking can also cause difficulties in maintaining focus on academic tasks, leading to lower achievement (Ophir et al., 2009; Wallis, 2010). Frequent multitasking is associated with a lower GPA (Bellur et al., 2015; Junco, 2012; Rosen et al., 2013; Walsh et al., 2013) since the time spent using digital media takes away from time devoted to academic activities. Junco (2012) found that overall GPA dropped 0.12 points for every 93 minutes above the average of 106 minutes per day spent on Facebook**.** Ophir, Nass, and Wagner (2009) suggest that high media multitaskers have poorer cognitive control abilities, meaning they have more difficulty managing attention and executive functions. This reduced self-regulation capacity makes it harder for them to focus on tasks and learn effectively, which can result in lower GPAs. Similar research by Rosen et al., (2013)**,** indicates that frequent task-switching caused by media distractions can diminish the quality of studying and negatively affect GPA. Lepp et al., (2014) confirm that the use of mobile phones and other media can pose a significant distraction that interferes with the learning process and lowers GPA. Additionally, Langberg et al. (2013) explore how self-regulation impacts academic success and emphasize that students with better self-regulation skills can more effectively manage distractions, including media multitasking, and achieve better academic results. To avoid distractions and remain focused on learning, selective attention is crucial (Dayan and Solomon, 2010). Learners need to understand their attention state and employ effective strategies to regulate their attention. If a student has a clear and specific goal and sufficient motivation, such as studying for an upcoming exam, they are less likely to multitask and vice versa (Judd and Kennedy, 2011).

Although numerous studies confirm a negative correlation between media multitasking and academic achievement, some also report small to moderate effects (Burak, 2012; Junco and Cotten, 2012;

Ravizza et al., 2014), as well as no correlation (Karpinski et al., 2012; Wei et al., 2012; Clayson and Haley, 2013). This indicates a lack of consistency among researchers regarding the correlation between media multitasking and academic achievement in high school and college students.

This topic is crucial because it provides empirical evidence on how digital distractions impact learning outcomes, helping educators and policymakers develop effective strategies to mitigate these effects and enhance student performance in educational settings. Our study is a meta-analysis and attempts to systematize the results of previous studies on the topic of the correlation between academic media multitasking for non-academic purposes and student achievement. This approach aggregates data from various studies to provide more robust conclusions, offering insights into the consistency and strength of the association between media multitasking behaviors and academic outcomes that individual studies alone may not achieve. A meta-analysis is important in this study because it allows for the comprehensive integration of findings from multiple studies, increasing statistical power and generalizability. Even though this field began developing more than a decade ago, the present times and unique environmental factors during the pandemic greatly increased its significance.

Materials and Methods

Variable operationalization

Academic media multitasking – operationalized through a questionnaire measuring the frequency of digital media use (social networks, email, games, websites, search engines, watching/listening to videos, talking on the phone) during academic activities, either in class or at home, for non-academic purposes. The scales research authors identified as adequate measures of media multitasking were also taken into consideration. These measure the use of various digital media during academic activities or assess attitudes about being able to efficiently follow lessons/complete tasks while using some of the media (e.g. social networks). The measures are intercomparable, and higher scores indicate greater frequency/inclination for multitasking.

Academic achievement – operationalized as the current GPA, the semester average grade, the average grade from the previous level of education (high school), or the average grade in compulsory subjects. All measures are equivalent.

Inclusion and Exclusion Criteria

In order to be included in the meta-analysis, the research had to meet the following criteria:

1. It was published in a scientific journal with an impact factor (Clarivate JCR).
2. The publication language of the journal is English.
3. The study is not older than 2010 (statistical data indicate a continuous increase in the use of the internet itself, as well as social networks at the end of the first decade of the 2000s, while Instagram, the currently most popular social network, was founded in 2010).
4. The independent variable relates to the use of media multitasking.
5. Media multitasking refers to the use of digital tools in an educational context for non-academic purposes.
6. The study must report correlation coefficients between the variables or provide sufficient data to calculate these coefficients. The correlation coefficient was chosen as the measure of effect size because it was consistently reported across studies, allowing for a standardized comparison of the relationship between media multitasking and academic achievement. This approach maintains the internal and external validity of the meta-analysis by ensuring that the effect sizes are comparable across different studies.
7. The dependent variable must be operationalized as an average grade (GPA or equivalent measure). GPA is used due to its standardization and comparability across different educational contexts and time periods, providing a reliable measure of academic performance. This decision helps maintain both internal and external validity by ensuring that the measure of academic achievement is consistent and comparable across all included studies.

After all the criteria were applied, 11 correlational studies were included in the final sample. The table with the studies contained in the sample can be seen in Appendix A.

Data Extraction Process

The data extraction process involved systematically reviewing each included study to obtain the necessary information for the meta-analysis. This comprehensive approach ensured that we had consistent and comparable data across all studies, which is crucial for maintaining the validity and reliability of the meta-analysis. For each study, we extracted detailed information including the study title, authors, year of publication, and the journal in which the study was published. We also recorded the impact factor (IF) of the journal to ensure the quality and credibility of the included studies. From the sample details, we documented characteristics such as the type of participants (e.g., students, adolescents), along with the sample size. Regarding the measures used, we extracted specific information on media multitasking, including the types of digital media use (e.g., social networks, email, games) and the context of use (e.g., during class or at home for non-academic purposes). Similarly, we noted the measures used to assess academic achievement, such as current GPA, semester average grade, or average grade from the previous level of education. Importantly, each study reported the effect size measure required for our analysis in the form of correlation coefficients. This consistency eliminated the need to use other statistics or perform additional calculations to derive these values. Each study provided a single relevant correlation measure between media multitasking and academic achievement, so there was no need to merge multiple effect sizes from individual studies.

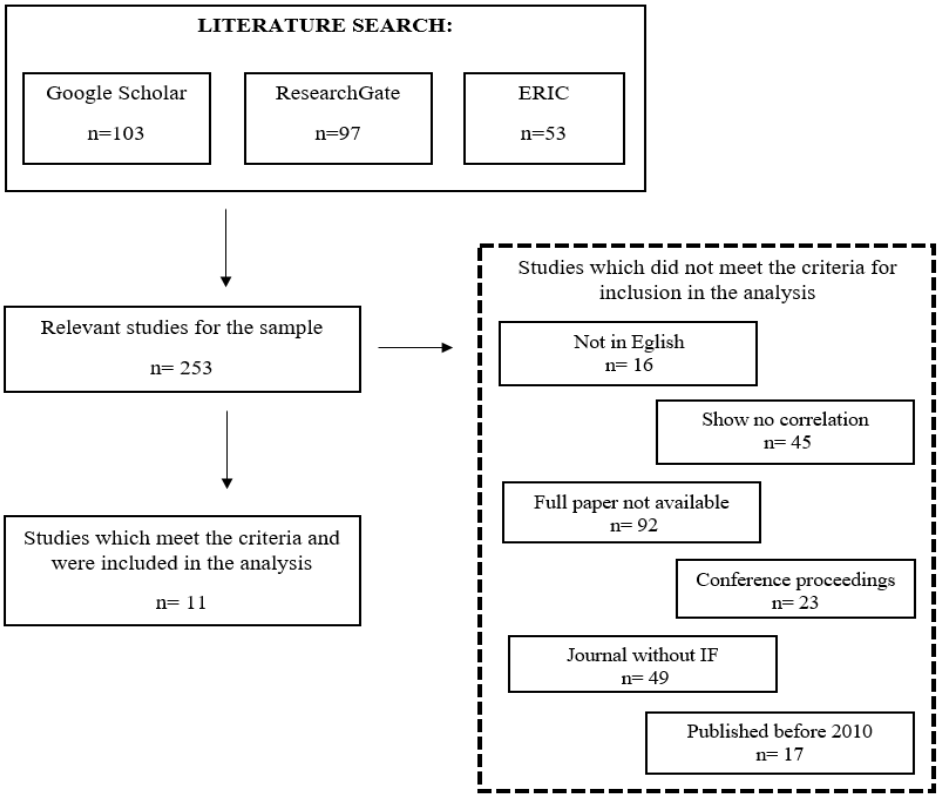
Quality Assessment of Studies

The quality of the included studies was assessed using established criteria to evaluate risk of bias and methodological rigor. This process involved a thorough review of each study's research design, data collection methods, and analysis techniques. To ensure a comprehensive and objective assessment, multiple researchers independently evaluated each study. Each study was first evaluated for potential sources of bias, including the selection of participants, measurement of variables, and control of confounding factors. Additionally, the methodological rigor of each study was assessed based on the clarity of research questions, appropriateness of study design, and robustness of data collection and analysis methods. The validity of the measures used for both media multitasking and academic achievement were also considered. To enhance the reliability of the quality assessment, three researchers independently coded each study. This involved assigning ratings for each criterion based on predefined scales. The initial ratings were then compared to identify any discrepancies. In cases where discrepancies were identified, researchers discussed the differences and reached a consensus on the final ratings. This quality assessment process ensured that the included studies were evaluated consistently and objectively, enhancing the validity and reliability of the meta-analysis.

Literature search

To ensure systematic and transparent reporting, we followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines throughout the review process. These guidelines provided a structured approach to conducting and reporting the meta-analysis, enhancing the reproducibility and credibility of our findings.

The literature search was conducted via available internet databases for accessing scientific publications that do not require special permissions, and are widely used in the scientific community: Google Scholar, ResearchGate, and ERIC. The keywords used in the search were: digital multitasking, digital distraction, media multitasking, cyberloafing, academic achievement, academic performance, GPA. The search was narrowed down to include only full-text articles published in 2010 and later. A review of the studies included in the analysis is shown in Graph 1:



Graph 1. Search and selection of works for analysis

Statistical Analyses

Correlation coefficients were used as a measure of the effect size of individual studies and the overall measure of effect size. There was no need for additional conversion of measures. The sample size was used for weighting the effect size. The participants from the original studies differ in age, level of education, country of origin, and potentially other covariates. Due to this, it is assumed that there is no distribution of true effects, indicating that a random effects model would be suitable for calculating the overall measure of effect size. Regarding the assessment of the existence of a "file drawer effect," i.e., the bias of the effect size measure in published versus unpublished studies, a symmetry graph of the of studies around the overall measure of effect size is shown, along with the results of the so-called Trim and fill analysis. The software used for calculating individual and overall measures of effect size is the trial version of Comprehensive Meta-Analysis.

Correlation coefficients were used as a measure of the effect size of individual studies and the overall measure of effect size. As these coefficients were consistently reported across all studies, there was no need for additional conversion of measures. The sample size of each study was used for weighting the effect size, ensuring that larger studies had a proportionately greater impact on the overall results. The participants from the original studies varied in age, level of education, country of origin, and other potential covariates. Due to this heterogeneity, it was assumed that there is no single distribution of true effects, indicating that a random effects model would be suitable for calculating the overall measure of effect size. The random effects model accounts for variability both within and between studies, providing a more generalized estimate of the effect size. Additionally, we assessed the potential existence of a "file drawer effect," which refers to the bias of effect size measures in published versus unpublished studies. This was done using a symmetry graph (funnel plot) to visualize the distribution of studies around the overall measure of effect size. The results of the Trim and Fill analysis were also presented to adjust for potential publication bias. The software used for calculating individual and overall measures of effect size was the Comprehensive Meta-Analysis (CMA). CMA provided the necessary tools for conducting both fixed and random effects models, as well as additional analyses such as the Trim and Fill method for assessing publication bias. By using both fixed and random effects models, weighted effect sizes based

on sample size, and following PRISMA guidelines, our analysis aimed to provide a robust and reliable synthesis of the relationship between media multitasking and academic achievement.

Results

As for the heterogeneity of the effect size measure, considering the values of the Q statistic and its statistical significance, the hypothesis of the existence of a fixed effect can be rejected. The results suggest that 93.98% of the total variance can be attributed to heterogeneity – variance between individual studies (I^2 = 93.985). This result can be interpreted as very high heterogeneity (Huedo-Medina et al., 2006).

Table 1. *Results of heterogeneity testing*

Heterogeneity			
Q	df	*p*	I^2
166.241	10	.000	93.985

Q – significance indicator of heterogeneity; I2 – percentage of total variability that can be attributed to heterogeneity

Table 2. *Random effects when calculating meta-statistics of correlation between media multitasking and academic achievement*

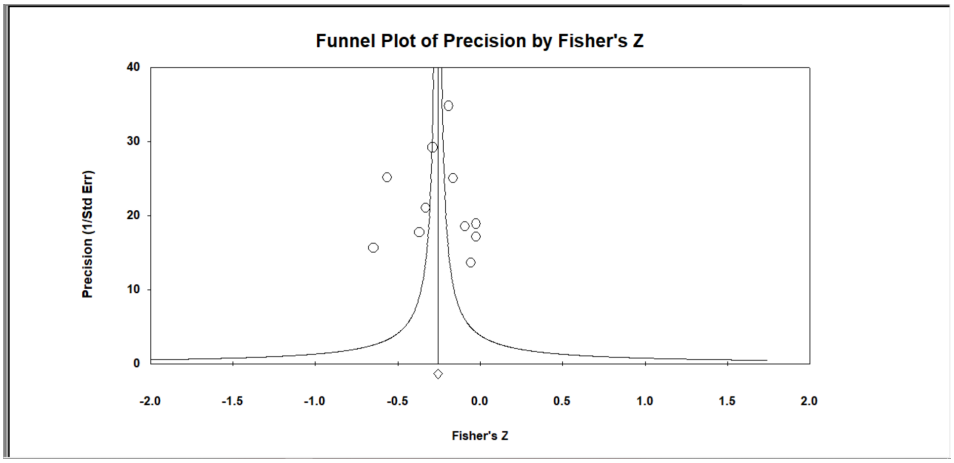
Effect size				*Test of Null*	
N	$\hat{r}$	GG	DG	*Z*	*p*
11	-.246	-.347	-.140	-4.465	.000

N – number of studies included in the analysis; $\hat{r}$ - weighted average correlation coefficient; GG – upper limit; DG – lower limit

The results indicate that the overall measure of effect size differs from zero after applying the random effects model (z= -4.465, p= 0.000), meaning there is a statistically significant negative correlation between media multitasking and academic achievement.

File Drawer Effect

The existence of the file drawer effect was also examined. This refers to the bias of studies included in the meta-analysis compared to those not included, which could have an impact on the overall measure of effect size. The results indicated that the overall measure of effect size does not differ with respect to the random and fixed effect model, therefore, the results are only shown for the random effects model in Graph 2.



Graph 2. File drawer effect for the random effects model

Graph 2 shows the file drawer effect for the random effects model. The studies included in the meta-analysis are represented by circles. They are evenly distributed around the vertical axis, and considering the fact that 11 studies were included in the analysis, a distribution of 6:5 can be considered equal. Therefore, a bias in the selection of studies for analysis can be excluded based on this graph.

Discussion

This meta-analysis aimed to quantitatively integrate works and draw general conclusions about the existence of a correlation between media multitasking and academic achievement. Media multitasking in an academic environment has been the focus of researchers' attention in recent years. This topic is gaining significance with the increasing application of teaching in an online environment. The idea for the research stemmed from a thorough review of the relevant literature and the observation of inconsistencies in the obtained results. Among the numerous studies that confirm a negative correlation between media multitasking and academic achievement, there are also those that report small to moderate effects or no correlation.

The results of this meta-analysis confirmed the existence of a negative correlation between academic media multitasking and academic achievement, as indicated by the obtained meta-statistics, i.e., the average weighted Pearson correlation coefficient. A low-intensity correlation was obtained. Most individual studies included in the meta-analysis report a low negative correlation, hence these results are within the expected range.

Analyses have shown that over 93% of the total variance can be attributed to heterogeneity, i.e., variance between individual studies. Such a result confirms the justification for using a random or variable effects model. Namely, when the I^2 statistic is of moderate or high intensity, there is a basis for further examination of the relationship between constructs, i.e., examining the impact of moderating variables that can explain heterogeneity (Sánchez-Meca and Marin-Martinez, 2010). In the presented meta-analysis, heterogeneity is very high, and this result indicates the need for further research. Given the results from the funnel plot analysis, there is no indication of a significant file drawer effect in this meta-analysis. The distribution of effect sizes appears relatively symmetric, suggesting that studies with both positive and non-significant results were included in the analysis without substantial bias in the selection process. This absence of a file drawer effect strengthens the validity of the findings and supports the robustness of the conclusions drawn from the studies included in the meta-analysis. However, while the visual inspection does not suggest a publication bias, it is important to note that the potential for undetected bias always exists, and further statistical tests could be employed to confirm these observations.

Today's adolescents have easy access to digital technology and often use it during other daily activities, which is why they can be referred to as 'multitaskers' (Demirbilek and Talan, 2018). Our sample consisted of research which included respondents in the early, middle, and late adolescence period, and the results of the meta-analysis indicate that frequent use of technology during academic activities for non-academic purposes is negatively correlated with academic achievement. The availability of technology, such as smartphones, allows students to switch between tasks during lectures (Ralph et al., 2020). Additionally, some students engage in multitasking to stay connected with friends or because they believe it is an efficient way to handle multiple tasks (Kuznekoff and Titsworth, 2013). Multitasking can also serve as a coping mechanism for boredom or stress during lectures (Wiradhany et al., 2021), while a lack of self-regulation may contribute to increased multitasking (Ralph et al., 2020). Furthermore, social pressure and the desire for interaction on social media can also play a role (Liu and Gu, 2019). It is widely known that human cognitive capacities are limited, i.e., working memory inhibits the ability of humans to process newly acquired information (Sweller, 1988). When media multitasking is intense or prolonged, it leads to cognitive overload, which impairs message processing and triggers stress responses, ultimately harming academic performance (Baumgartner and Wiradhany, 2021). Switching from one task to another or performing multiple tasks during academic activities requires a change in focus, cognitive work, and attention (Demirbilek, and Talan, 2018), which can explain the negative correlation with academic achievement. Cognitive load increases due to frequent activity changes (Paivio, 1986), performance decreases as a result of simultaneous activities (Junco and Cotten, 2012), and the completion of activities is delayed (Bowman et al., 2010). Previous research suggests that attention problems in the academic context, i.e., difficulties in directing and maintaining attention, may be at the core of multitasking, and can lead to lower academic achievement (Ophir et al., 2009). Additionally, insufficient investment of time in completing academic tasks will result in decreased use of one's potential (Fox et al., 2009). Other correlational

research points to a small to moderate negative correlation between academic media multitasking and achievement (e.g., Junco and Cotten, 2012; Ravizza et al., 2014).

Conclusion

When it comes to the construct of academic media multitasking, the existence of deviations in operationalizations and instruments used in primary research prompted the author of this meta-analytic study to rely on journal credibility, as well as on the subjective assessment of the adequacy of operationalization. Only the studies which met the set quality criteria were included in the analysis. Furthermore, the analysis of bias in the selection of primary research showed that there is no file drawer effect. Studies included in the analysis were published in leading scientific journals with a high impact factor, which is one of the indicators of the quality of the study. On the one hand, the limitations of this study are reflected in the small sample of primary research which were included in the meta-analysis process (N=11), although, on the other hand, this can be viewed as an advantage due to appropriateness, quality, and credibility of the data contained in the final selection of articles.

Given that this meta-analysis was conducted on a sample of correlational studies, causality can be ruled out. Other explanations and possible confounding variables should also be considered. Although it might seem less likely, poorer achievement can negatively affect the motivation to engage in academic activities, which in turn promotes multitasking. However, despite the aforementioned limitations, this meta-analytic study has primarily theoretical implications in terms of its contribution to a better understanding of the phenomenon of academic media multitasking and academic achievement. The present meta-analysis not only confirmed the value of previous studies, but also paved the way for exploring potential mediating relationships or covariates affecting reasons why students engage in media multitasking. Future meta-analytic studies dealing with the topic are recommended to consider the moderating impact of some other variables from the domain of personality, self-regulation skills, and motivation.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization – K. C. and N. L.; Data Curation – M. V. and J. K.; Formal analysis – K. C. and Jelena O. K.; Investigation – N. L. and J. K.; Methodology – J. O. K. and K. C.; Project Administration – K. C. and N. L.; Visualization – J. K. and M. V.; Writing original draft – K. C. and N. L.; All authors have read and agreed to the published version of the manuscript.

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Appendix A:

Table 1. *The studies contained in the sample*

Study	Authors	Year	Journal	IF	Sample	Sample size	Multitasking	Achievement	r
1	Bellur, S., Nowak, K. L., & Hull, K. S.	2015	*Computers in Human Behavior*	6.829	Students	361	Multitasking during homework (Bellur, Nowak, & Hull, 2015)	High school GPA	−.025
2	Karpinski, A. C., Kirschner, P. A., Ozer, I., Mellott, J. A., & Ochwo, P.	2013	*Computers in Human Behavior*	6.829	Students	857	Multitasking with SNS while studying (Karpinski, Kirschner, Ozer, Mellott, & Ochwo, 2013)	GPA	-0.28
3	Kokoç, M.	2021	*Scandinavian Journal of Psychology*	2.25	Students	637	Multitasking with Social Media (Ozer, 2014)	GPA	–0.51
4	Lau, W. W.	2017	*Computers in human behavior*	6.829	Students	348	Multitasking with Social Media (Ozer, 2014)	GPA	-0.092
5	Luo, J., Yeung, P. S., & Li, H.	2020	*Children and Youth Services Review*	2.393	Adolescents (12-18)	447	Media Multitasking Scale (MMS) (Luo et al. 2018)	Current average grade for all school subjects	−0.32
6	Raza, M. Y., Khan, A. N., Khan, N. A., Ali, A., & Bano, S.	2020	*Journal of Public Affairs*	1.08	Students	248	Media multitasking (Lau, 2017 adapted from Ozer's, 2014)	GPA	−0.57
7	Uzun, A. M., & Kilis, S	2019	*Computers in Human Behavior*	6.829	Students	631	Sub-dimension Multitasking Preference of the attitudes subscales of MTUAS (Rosen et al., 2013)	GPA	-0.164
8	van der Schuur, W. A., Baumgartner, S. E., Sumter, S. R., & Valkenburg, P. M	2020	*New media & society*	8.061	Adolescents (11-15)	1215	AMM (van der Schuur, Baumgartner, Sumter & Valkenburg, 2020) based on the Media Multitasking Index (MMI) developed by Ophir et al. (2009).	Academic achievement scores	−.19
9	Wei, F. Y. F., Wang, Y. K., & Klausner, M.	2012	*Communication Education*	1.759	Students	190	Text messaging during class (Wei & Wang, 2010)	AP, traditional academic performance (grade-oriented learning)	-0.056
10	Legkauskas, V., & Steponavičiūtė-Kupčinskė, I.	2021	*Education and Information Technologies*	2.917	High school students	319	In-class use of social media (Legkauskas & Steponavičiūtė-Kupčinskė, 2021)	GPA	−0.353
11	Clayson, D. E., & Haley, D. A.	2013	*Journal of Marketing Education*	3.122	Students	298	General attitudes toward texting (Clayson & Haley, 2013)	GPA	−.025

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Cross-modal Priming of a Music Education Event in a Digital Environment

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Abstract: This study aims to explore the potential of the digital environment for implementing a multimodal approach in music education. The effectiveness of information received through a combination of sensory stimuli demonstrates a higher coefficient of educational efficiency and is examined as cross-modal priming. Digital technologies: including specialized and educational software, virtual instruments, and artificial intelligence (AI), transform the music education experience into an accessible resource for individuals with limited musical abilities or non-professional knowledge in the field of art. This justifies their consideration as tools for general music education. The study presents a model for applying specialized music software in the perception of a musical piece by students (aged 12–13), as well as a methodological framewoamong university students, future kindergarten and primary school teachers. The findings indicate improved musical-cognitive outcomes and a high evaluation of specialized software as a didactic tool among university students. Additionally, the study discusses the role of AI in music education.

Keywords: *cross-modal, priming, music, education, specialized software, AI.*

Introduction

In the era of digital transformation, education and the arts are undergoing significant changes, creating opportunities to optimize aesthetic education through interactivity and accessibility. The correlation *music-education-digital technologies* expands the practical and applied aspects of music learning, providing a rich toolkit for artistic interaction (Falkner (1995); Pastarmadzhiev, 2021; Bačlija and Mičija, 2022; Rexhepi, Breznica and Rexhepi, 2024). The complex of sensory stimulus in perception of an object in time-space behavior, organizes the cognitive activity. In general educational musical interaction, conditions for functioning of such a complex of stimulus, is provided in the digital environment. Digital technologies visualize interactive musical text, individualizing the interaction, providing tactile activity.

A study based on the VARK model (Fleming and Baume, 2006) was conducted by Mishra, 2007, analyzing educational strategies for learning to play a musical instrument. The process of performing a musical piece involves reading notation, motor cognition related to the instrument's sound production, systematic praxis for memorization, and artistic interpretation.

Traditional forms of musical engagement are realized through three primary activities: perception, performance, and composition. These activities are interrelated, with perception forming the foundation of music production. This underpins extensive research on multisensory reactivity to sonic structures. Even since 1994 Robert Dunn (Mishra, 2007, p.5) *assumed that the musical perception* responds to sound, motorial, and visual stimuli, regardless of individual modality. His study reports the following findings**:**

- 19% respond only to auditory stimuli;
- 50% to both visual and auditory stimuli;
- 6% to auditory and motor stimuli;
- 25% to a combination of all.

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Unlike Dunn's study, Falkner's findings indicate that kinesthetic learning plays the most significant role - 50%, compared to 22%- auditory and 28%- visual. These differences are substantial, as interpretative musicianship belongs to the realm of performance, even though perception remains a reflective process. Furthermore, Jennifer Mishra (Mishra, 2007) explores the relationship between perception and memory encoding of auditory information among instrumental musicians. Initially, she analyzes *121 studies* related to the process of musical memorization. In 60% of them, she identifies a scientific focus on auditory, visual, and kinesthetic styles, while 51% **-** emphasize their combination to optimize educational outcomes. These studies highlight the complexity of musical events and the unique nature of musical communication within the framework of multisensory interactions, functioning as cross-modal priming.

Music is structured within strict algorithmic dependencies, defined by pitch and rhythmic relationships. It carries semantic markers with emotional and conceptual projections that shape the perception process. This distinctive dual structure positions music as a system of modes within the broader field of information transfer. The integration of musical activity into a digital environment, driven by the pursuit of singularity, establishes an accessible model that seamlessly incorporates both educational and specialized music software, as well as the increasingly advanced frameworks of artificial intelligence (AI). The synergy between learning styles, embedded within various digital productions, influences perception by delivering information as a complex interplay of sensory stimuli within a given time frame. The study in this paper is dedicated to the crossmodally in perception of sonorous flow.

Materials and Methods

Learning through computing technologies eliminates intellectual passivity. This can be explained by the way the system itself is structured, based on a database and models for constructing cognitive activity. Computing technologies possess a set of capabilities:

- Diverse and large volumes of information
- Goal setting and behavior planning following the sequence: goal – plan – actions
- Partial selection of the necessary database
- Utilizing available knowledge and reasoning results corresponding to set goals
- Justifying decisions in practice and realizing them in achieved results
- Conducting reflection – evaluation of knowledge and actions
- Stimulating cognitive curiosity – encouraging learners to ask questions independently
- Data monitoring
- Supporting the rationalization of ideas and striving for conceptual clarification
- Interpreting a comprehensive picture of the subject of cognitive activity, integrating knowledge relevant to the set goal
- Correcting and adapting the final result according to changes in the cognitive situation
- The cognitive activity carried out through them is organized into resource modules:
- Data and knowledge representation
- Reasoning and computation
- Multisensory communication – ensuring accessibility and convenience in interaction with the computer

One of the most innovative approaches in this field is cross-modal priming—a method that employs multisensory stimulation to enhance learning and memory retention. When applied to music education events in a digital environment, cross-modal priming can play a pivotal role. Multisensory communication in musical art involves a stimulus (prime), that aligns with the recipient's cognitive predispositions. Subsequently, this stimulus in one modality (visual, auditory, tactile, or semantic) influences the processing or perception of another stimulus in a different modality. This influence may manifest as a faster response, easier recognition, or improved retention of the second stimulus. The network of stimuli that conditions this response is defined as cross-modal priming.

Figure 1 presents a universal model of cross-modal priming in an educational environment, using specialized software as a tool.

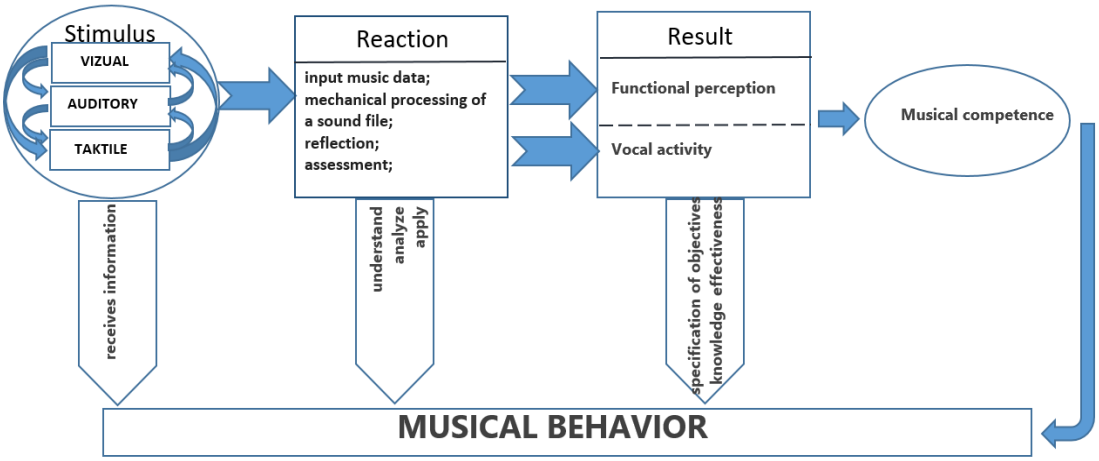


Figure 1. Correlation cross-modal priming-musical behavior

An original methodology for perceiving a musical piece through specialized music software (Sibelius and FL Studio), developed for students in the primary stage of secondary school, includes the following activities:

1. Notation of the theme in interactive mode (each entered written symbol is played back)
2. Reflection on the recording – listening, analyzing, and correcting the notated theme
3. Listening to the musical piece and auditory recognition of the notated theme
4. Creating an audio file by extracting the notated theme from the musical piece
5. Audio processing and arranging the theme from the piece using the respective software tools

Each stage involves visual, auditory, and tactile stimuli. Method for performance of a song by students, the future teachers also include five stages:

1. Notation of the song using the MuseScore software
2. Listening to the notated recording
3. Learning the song
4. Planning activities related to artistic performance and making corrections to the score
5. Artistic performance of the song

Research question goals and objectives

Investigation is based on the role of digital environment for improvement of cognitive-educational musical activity. The goals of the current investigation are to be presenting models for musical educational activities in digital environment and proving the effectiveness of the cognitive activity, based on cross-modal technology for perception of sonorous information flow.

The transfer of a music education event to a digital environment optimizes performance and provides a complex set of sensory activities in the perception process. The application of music software in a music education event offers an innovative perception model that corresponds to both listening to music and performing it. Learning with the help of music computing technologies redistributes the involvement of visual and auditory analyzers by incorporating the mechanical process of data input. The transition from sensation and perception to thinking is mediated by mental representations, depending on their type (visual, auditory, motor) and the content of the sonorous product. The current investigation involves the following computing capabilities (see, chapter Materials and methods): (1) data and knowledge representation; (2) reasoning and computation which I assume to become my independent variables and is defined, based on the intelligence of the computing system—the ability to manage new knowledge through the use of available database information as reasoning, defined to be independent variables, expressed through their corresponding indicators:

1. Writing of a music text with the help of a notation software (Sibelius 6 and MuseScore 3.6)
2. Listening to the notated recording

3. Memorizing of a musical composition
4. Analysis of a sonorial structure
5. Development of a creativity product

The management of the information flow is based on *deductive reasoning*, as the algorithm of activity follows the principle of transferring correctly embedded information to conclusions or inferences. Along with the database, computing system software includes rules and axioms that guide and revise the results of the activity.

M*ultisensory communication,* (see, chapter Materials and methods): supports the development of musical hearing and musical behavior through logical-perceptual forms and emotional-reactive expressions in actions and appears to be the dependent variable through its indicators of statistical significance. It is "effective transformation in the course of multimodal education fulfilled in experience" (Dermendzhieva and Tsankov, 2022, p.168). Understanding musical expressive means is facilitated by the cross-modality of priming. When working in a music software environment, the stimulus combines visual, auditory, and motor sensibilities.

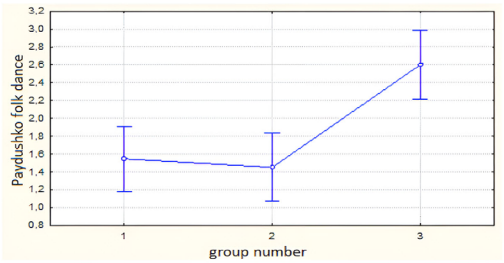
The controlled variable of my investigation is the selected software MuseScore, version.3.6.1 for notation in the performance; Sibelius 6 for perception; FLStudio 9.6 for audio-processing and arranging.

Experimental data

The experiment perception of musical work was conducted with two control groups and one experimental group (students aged 12–13). The obtained results (Table 1) for auditory recognition of a musical piece, at a 5% significance level ($F = 11.259$, $p < 0.0007$), indicate that the experimental group achieved higher performance, with the statistical difference being significant (Petkova, 2023, p.108).

Table 1. *Statistical analysis of data and study performance*

ANOVA Result "Payduchko horo"	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	16,489	2	8,245	11,259	,000
Within Groups	43,205	59	,732		
Total	59,694	61			



The model for vocal performance was conducted with students, future teachers in kindergartens and the primary stage of general education schools (Petkova, 2022). The software used was MuseScore, with the goal of mastering a model for organizing vocal activities and learning the notated song as an object of music-pedagogical communication. The developed methodology aligns with regulatory documents that assign arts classes to all certified teachers: kindergarten teachers (ages 3–7) and primary school teachers (ages 7–11). In the current study, the presented indicators, (see chapter Research question goals and objectives) as input characteristics were applied.

A total of 102 students participated in the study. Among them, *70 students* (68.63%) wrote the notes *without errors. Ten* students (9.80%) made *one mistake* each, and *22 students* (21.57%) made *more than one mistake.*The calculation of the average number of mistakes is as follows:

$(10 \times 1) + (22 \times 2) = 10 + 44 =$ *54 mistakes*; thus, the average number of mistakes per student is:

$54 / 102 \approx$ *0.53 mistakes per student.*

This result indicates that each student made fewer than one mistake on average, which is a good indicator of success.

Results and Discussions

The initial stimuli are maintained through necessary actions to reveal the educational value of the subject of the educational event: either an instrumental piece or a song. The response is algorithmically

controlled by the training parameters embedded in computer programs, meaning that errors can only occur in the pitch of the musical sound. This characteristic requires systematic auditory reflection, while simultaneously involving the input of musical notation, which is linked to observation and its transfer into an interactive digital environment. The outcome in both models is musical activity— perception and performance. Cross-modal priming also ensures the cross-modality of musical activities. During the perception phase, auditory representations of the theme from the instrumental piece are formed. Auditory observation is supported by a visualization of the sound structure, which also enables solfège (performance). The result of notating a song is its performance, which combines both perception and execution. This standardizes the process of developing skills necessary for engaging in musical activities.

This structured approach integrates into an operational model that transforms into musical competence. Musical competence is equivalent to musical behavior, as all independently initiated forms of musical activity, resulting from the internalization of the educational event, stem from competencies acquired through cross-modal priming. A conducted survey on the attitudes toward applying specialized software in music education in kindergartens and grades 1–4 found that 84% of students indicated they would use digital resources to support educational activities—76% for perception activities and 84% for song performance.

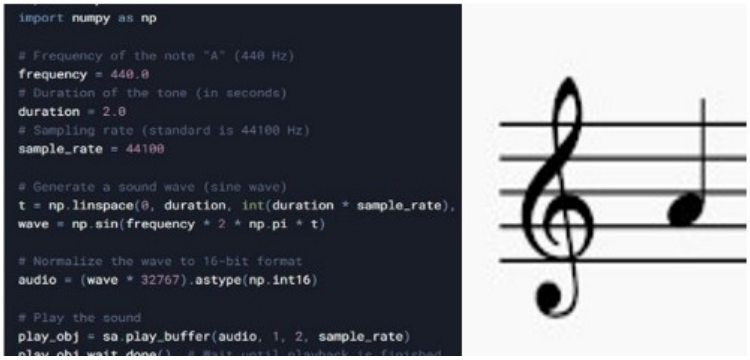
Artificial Intelligence (AI) emerges as a natural extension of the development of digital technologies. An increasing number of algorithms are embedded in technology to ease and optimize human activity. A new, rapidly growing industry is being built around various AI services offered worldwide for the creation, processing, and analysis of music.

Future in cognitive studies

Virtual models of musical activity are supported by specialized educational software products and AI. Musical communication is built on the interaction between sensory stimuli and the analysis of the sonorous structure in terms of pitch, meter-rhythm, timbre, and dynamic responsiveness, synchronized with the semantic value of the musical piece for the recipient.

Platforms such as OpenAI, ChatGPT, and ChatGPT Plus are based on GPT models available at chat.openai.com and generate information based on strategically formulated questions (Holster, J. 2024). Applications have been developed that analyze musical structures by recognizing audio pieces (*Shazam*), support sound environments to enhance intellectual activity (*Brain FM*), or analyze users' aesthetic preferences (*Spotify*). A major focus of many projects is exploring AI's ability to autonomously generate music or collaborate with composers. An example is the European Research Council-funded project *Flow Machines by Sony CSL* (Sony CSL, 1993–2025). *Google Magenta* (Magenta.js, 2023) is a research project launched by Google that investigates the role of machine learning in creating synthetic music products. Algorithms for generating songs have been developed. **Aiva**, created by AIVA Technologies, has an AI script capable of composing "emotional" soundtracks for advertisements, video games, or films, as well as creating variations of existing songs. The first generator to create a musical structure based on emotional analysis is *Melodrive* (Melodrive, 2025), while *IBM Watson Beat* is a project with the ability to harmonize melodies.

When analyzing the digital environment, it is important to consider that AI is rapidly gaining popularity. It learns communication models through text and integrates into specialized music software. The integrative potential of AI can be explored in the fields of text processing and sound generation using code in various programming languages. From the perspective of the syntax of a musical event, this shifts the focus to an alternative symbolic system, distinct from traditional musical notation. In Figure 2, an example code snippet is presented for generating a musical tone with a frequency of 441 Hz corresponding to the note "a^1" with a duration equivalent to a quarter note, alongside a notation of the same event in the specialized scoring software *MuseScore*.



```
import numpy as np

# Frequency of the note "A" (440 Hz)
frequency = 440.0
# Duration of the tone (in seconds)
duration = 2.0
# Sampling rate (standard is 44100 Hz)
sample_rate = 44100

# Generate a sound wave (sine wave)
t = np.linspace(0, duration, int(duration * sample_rate),
wave = np.sin(frequency * 2 * np.pi * t)

# Normalize the wave to 16-bit format
audio = (wave * 32767).astype(np.int16)

# Play the sound
play_obj = sa.play_buffer(audio, 1, 2, sample_rate)
```

Figure 2. Tone code „a[1]“

The primary approach to developing an AI skill is the definition of a semantic network, which enables "the process of constructing, linking, and representing generalized concepts" (Kordon, 2023, p.36). At this stage, in a digital environment, crossmodal priming operates more effectively within specialized music software. For example, when entering the note "a[1]" on an interactive score sheet in notation software (such as MuseScore, Sibelius, etc.), the user hears, sees, acts, and understands (learns) the meaning of this symbol. When working with *AIVA or SUNO* (AI for music creation), the user defines the semantic model of the product by specifying the musical style, content, and mood. Once the *sonic model* is generated, some of its parameters can be edited.

The educational benefits of this music-technology activity manifest in a remote projection of the creative process, based on emotional needs. Here, the user does not participate in the spatiotemporal organization of musical activity but acts as a mere consumer (Grigorova, 2018) of a pre-designed model. Even though the user initiates the creation process, they remain in the role of a listener, with only "the personal function of perception" being active (Baleva, p. 66, 2010). The result is a product with emotional, stylistic, and textual parameters tailored to the recipient's needs. Whether the auditory structure functions as a true creative process or merely as a musical activity is a matter of perspective. From the standpoint of music education, the achievement lies in defining the parameters of the final product, determining its content and style, without direct interaction with the sonic material.

Conclusions

The analysis of the digital enviro*nment* in the context of music education reveals various application possibilities. The diversity of resources that enhance multimodal learning through multisensory perception enriches the learning space. The semantic nature of musical art, along with its spatiotemporal functioning, creates a system of modes that interact within musical activity. The trends in digitalization align with the goal of universalizing and optimizing the operational model of musical activities. The visual-sonic-tactile correlation in structuring the audio model within a digital environment ensures information accessibility through crossmodality *in* multisensory arrangement. The greatest advantage is the materialization of the project into a musical-creative activity, presented as an interactive digital product. The influence of AI in education is rapidly growing, but text-based models still dominate. The machine models developed for music have yet to integrate the ability to "read" musical notation. However, for crossmodal priming, it is crucial that visual, auditory, and tactile elements are linked to an understanding of musical syntax. The future of AI in music education remains an open field for further research.

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Conflict of interests

The authors declare no conflict of interest.

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Educators' Views on the Impact of Traditional Music on the Socio-Emotional Competencies of Preschool-Aged Children

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Abstract: This study aims to present educators' views on the importance of incorporating traditional music during activities with preschool-aged children to develop their socio-emotional competencies. The sample consisted of 88 educators from preschool institutions in the Republic of Serbia. The results showed that most educators frequently use traditional music in their work. Its significance for the development of emotional intelligence, social skills, and cultural awareness in children was particularly emphasized. The analysis showed that educators who regularly incorporate traditional music content report higher levels of socio-emotional competencies in children, highlighting the importance of this practice. Although the educators' age, work experience, and place of residence did not have a statistically significant impact, regional differences were observed. Educators in different parts of Serbia assessed socio-emotional competencies in a specific way, reflecting the cultural and pedagogical particularities of those regions. The conclusions confirm the importance of integrating traditional music into preschool curricula as a way to develop socio-emotional competencies and children's cultural identity. The research contributes to the understanding of the role of cultural heritage in the contemporary educational context, providing recommendations for further improvement of pedagogical practices.

Keywords: *music education, socio-emotional development, cultural heritage, musical content.*

Introduction

The preservation of a nation's identity is contingent upon the safeguarding of its traditions, customs, and historical legacy. Traditional music occupies a distinctive position within this cultural framework, serving as an invaluable component of the nation's intangible heritage. The lyrical content, melodic structures, and rhythmic patterns of traditional music serve as reflections of the cultural identity of the communities that have created it and the geographical regions in which it has developed. Across diverse cultural contexts, traditional music functions as a conduit for storytelling, emotional expression, and the transmission of values and beliefs. Examples of this include European folk ballads, African drumming traditions, and Asian court music. These traditions have been used by societies to foster a sense of community and continuity across generations.

The role of traditional music in cultural heritage is multifaceted and deeply embedded in various aspects of cultural identity. Elements such as folk songs, dances, and instruments shape communal experiences and preserve historical narratives. Beyond performance, these traditions extend to costumes, customs, and rituals, reinforcing connections to cultural roots. Ethnomusicologists highlight that traditional music serves as an educational and socializing tool, transmitting knowledge, values, and customs across generations (Nettl, 2005). This function underscores its essential role in preserving and perpetuating cultural heritage. It is widely acknowledged that traditional music, and folk music in particular, serves as a vital medium for the expression and maintenance of cultural identity. Research indicates that exposure to traditional music and play has a significant impact on child development, addressing their fundamental

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needs for creative expression and physical movement (Pavlović and Trakilović Milićević, 2013). As an integral part of cultural expression, it not only serves as a core element of heritage, but also encompasses various other cultural aspects and traditions (Özdek, 2015). The interplay between heritage narratives, the roles of those who engage with them and the material aspects associated with them has a significant impact on how heritage is interpreted, maintained and passed down through generations (Brandellero and Jansen, 2014). In Serbia, as in many other countries, traditional music constitutes a crucial component of national heritage. The incorporation of fundamental movement elements, such as walking, running and jumping, in folk dances like "kolo" and "poskok", offers a multifaceted approach to physical and social well-being. These types of activities strengthen the sense of community and belonging, which is particularly important in forming a positive attitude towards one's own culture and tradition (Jeremić and Milenović, 2020). Such dance forms are not unique to Serbia; they can be found across the globe in diverse cultural expressions, including Ireland's céilí dancing, Greece's syrtos, and Argentina's zamba. These examples underscore the global significance of traditional music in fostering a sense of belonging and identity. The Kodály concept and the Táncház method have been formally recognised by UNESCO for their role in preserving cultural heritage. Despite the influence of digital media on contemporary students, folk traditions remain essential components in educational curricula. Research findings provide insights into students' musical literacy and their connection to Hungary's cultural heritage (Buzás and Sagrillo, 2019).

The integration of traditional music into early childhood education is of pivotal significance in the realms of both cultural preservation and child development. In Serbia, the preschool education system is structured to promote children's holistic development, encompassing cognitive, socio-emotional, and physical growth. A significant initiative in this regard is the "Year of Advancement in Preschool Education," a program introduced to modernize and enhance the quality of preschool education. This initiative entails a paradigm shift from rigid, teacher-centred instruction to a child-centred approach, fostering creativity, exploration, and active learning. The initiative is designed not only to facilitate knowledge acquisition but also to encourage the practical application of skills, creativity, and cultural awareness (Vukićević, Golubović Ilić, and Stanojević, 2016). The Year of Advancement in Preschool Education signifies a substantial reform in Serbia's early childhood education system, aligning with key international documents such as the Convention on the Rights of the Child (1989) and incorporating contemporary pedagogical approaches. The programme has been developed to redefine the role of preschool education by emphasising the child's active participation, individuality, and creativity. It is argued that this approach fosters holistic development, ensuring that children are prepared for formal schooling and develop essential skills for lifelong learning. These competencies encompass communication in the mother tongue, mathematical, scientific, and technological literacy, cultural awareness, and creative expression (Pavlović, and Trakilović Milićević, 2013). Despite the fact that the programme under discussion is not directly related to traditional music, it is mentioned in this study because the research was conducted in a preschool institution that applies its principles. Comprehension of its framework is imperative for contextualising the influence of novel teaching methodologies on children's cultural development. The Year of Advancement programme is predicated on child-led, exploratory learning, and the integration of traditional music is congruent with its pedagogical foundations insofar as it offers opportunities for self-expression, creativity and social interaction. Despite the considerable advances made by this programme in the field of child-centred education, the connection to traditional music remains largely unexplored. It is widely acknowledged that early childhood is a formative period for developing a sense of cultural identity. Consequently, the incorporation of traditional music into preschool curricula provides children with a meaningful and interactive way to engage with their heritage. Activities such as singing folk songs, participating in traditional dances, and playing folk instruments offer children opportunities for creative expression, while also facilitating the development of critical social and emotional skills, including cooperation, empathy, and confidence.

A plethora of research has been conducted on the subject of the benefits of traditional music in early childhood education, with a particular emphasis on its role in fostering emotional expression, creativity, and motor skills. The active nature of children is evident in their spontaneous musical exploration, which helps them understand rhythm, melody, and movement while engaging in social interaction. It is further suggested that early exposure to traditional music encourages children to develop a connection with their cultural background while also fostering appreciation for other cultures. Customs, Folk Costumes, Song, and Dance are woven into all aspects of life and, as such, are passed down through generations as the identity of a people. The significance of folk tradition for the lives and work of people, in general, is de-

picted through the daily routine, which includes inherited elements woven into actions that individuals may not even notice. Preserving national identity and traditional values in times of general identity and cultural crises is a complex and crucial task in all segments and stages of the educational process (Vukićević, Golubović Ilić, and Stanojević, 2016). Through play and song, people have always expressed their feelings and linked them to everyday magical and religious rituals. Even in that period, the importance of play for both the individual and the community can be seen. The exact time of the origin of play cannot be determined, as it is lost in the distant past, where the first visual sources are found in cave paintings from the Stone Age. Regardless of the time of origin of folk games and folk tradition in general, one's tradition and culture must first be recognized, and this should be done "in early childhood, or in the younger school age. To achieve this, students need to encounter these contents through various subjects, while also utilizing the opportunity for correlation" (Sudzilovska, Ćalić, and Ivanović, 2012, p. 258). Children at an early age, through play and song, spontaneously absorb the spirit of folk music, learning about its specifics, rhythms, and steps of traditional dances. This fosters a sense of belonging to cultural heritage and a positive attitude toward other cultural heritages.

Theoretical Foundations

The influence of traditional music on the development of socio-emotional competencies (SEC) in preschool children necessitates the integration of theoretical and empirical perspectives, connecting cultural tradition, music, and early childhood development. This section draws from multiple theories and their concepts to establish a comprehensive framework.

The Theory of Socio-Emotional Development

The Social Emotional Competence (SEC) is a pivotal component of children's comprehensive development, encompassing the capacity to recognise and manage emotions, establish relationships, demonstrate empathy, and engage in cooperative activities. In accordance with Lev Vygotsky's (1978) sociocultural learning theory, interaction with the environment and learning through joint activities play a crucial role in development. Traditional music, as a medium of socialisation and cultural heritage, has the potential to facilitate socio-emotional learning, particularly through group activities such as singing and games. Engaging in such musical activities enables children to acquire essential competencies, fostering cooperation, empathy, and self-expression. This theoretical foundation underscores the notion that children thrive through active engagement in social and cultural activities. The application of these principles within the context of early childhood education facilitates a more profound comprehension of the role of traditional music in facilitating learning through interaction and the sharing of experiences. Empirical evidence has demonstrated that music engagement in early childhood fosters socio-emotional and identity development (Barrett, 2011; Custodero, 2005).

The Role of Music in Child Development

Music is a universal medium that encourages emotional expression, develops creativity, and facilitates the establishment of social bonds. According to research by Elliott and Silverman (2015), music in early childhood contributes to the development of a sense of belonging, empathy, and positive emotional experiences. Singing and traditional music-related games allow children to express their emotions and enhance teamwork abilities. Research in music psychology highlights its ability to promote positive emotions, reduce stress, and improve interpersonal relationships (Thaut, 2007). Furthermore, studies have demonstrated that structured musical activities contribute to emotional intelligence and cooperative behaviours in early childhood education (Koops, 2014; Hallam, 2010). It is evident that traditional music, with its uncomplicated rhythms and melodies, is particularly well-suited to young children, providing an accessible point of entry into the domain of music-making (Good et al, 2021; Li, 2013). Through the medium of singing and musical games, children are able to express their emotions, develop teamwork skills, and refine movement coordination.

Traditional Music as a Cultural Resource

Traditional music integrates elements of cultural heritage and customs that play an important role in the formation of identity. From the perspective of the theory of multicultural education (Banks, 2016), familiarity with national musical heritage influences the development of children's cultural and socio-emotional identity, fostering tolerance and acceptance of other cultures. Traditional music is a significant aspect of cultural identity and social heritage. Its place in the life of an individual and a community is not only a source of aesthetic enjoyment but also a means of transmitting values and customs across generations (Pavlović, and Trakilović Milićević, 2013). From the standpoint of the theory of multicultural education, introducing children to national musical heritage promotes a sense of belonging and openness toward different cultures (Banks, 2016). Research further supports this argument by demonstrating that traditional songs and games contribute to the formation of cultural identity in early childhood education (Marsh, 2010). Nursery rhymes, with their unique compositional characteristics, have been identified as a potent medium for fostering intercultural values. These rhymes not only facilitate the comprehension of one's own cultural values but also promote the recognition of cultural characteristics in other cultures (Villodre, 2014).

Psychological Effects of Music

According to research in the field of music psychology, musical content can stimulate the release of happiness hormones (endorphins), which influence positive mood and stress reduction (Thaut, 2007). Traditional music, with its simple rhythms and melodies, is particularly suited for children, creating an environment that promotes joy and social interaction. Traditional music, with its repetitive and melodic characteristics, provides children with a sense of security and encourages social interaction. These aspects are particularly crucial in early childhood, as children learn through emotional experiences and play. Studies indicate that music engagement fosters positive mental well-being and reduces anxiety, supporting children's overall development (Hallam, 2010).

Practical Applications in Preschool Education

Activities that involve traditional music allow preschool children to develop key competencies. For example, group singing and performing folk dances encourage the development of social skills, such as cooperation, listening to others, and movement coordination. The social aspect of teaching (socializing, group work), as well as the sense of empathy in children (self-esteem, sense of personal worth), is an important factor in their motivation, achieved through singing and performing traditional folk songs (JJeremić, Milenović, Petrović, and Markov, 2022). Practical applications of traditional music in preschool education include activities such as group singing, dancing, and performing folk games. These activities enable children to develop cooperation, coordination of movements, and social awareness (Elliott and Silverman, 2015). Authors (Sudzilovski, and Tanasković, 2022) emphasize the importance of content correlation in education, where traditional music can be integrated into various subjects, ensuring the holistic development of the child. Additionally, incorporating musical activities enhances cognitive, emotional, and social learning, supporting a well-rounded educational approach (Good, 2021).

Role of Traditional Games in Child Development

Traditional games represent not only physical activity but also a significant social phenomenon that encourages a sense of community. They involve basic movements such as walking, running, and jumping, while simultaneously developing both the physical and social aspects of a child's personality (Pavlović and Trakilović Milićević, 2013). Introducing traditional games through singing and playing contributes to a child's overall development. (Jeremić and Milenović, 2020). Traditional games help kids learn social skills, emotional management, strategic thinking, and problem-solving. Ashar et al. (2024) emphasise that traditional games play a crucial role in enhancing children's socio-emotional skills, fostering teamwork, and promoting cultural identity. Similarly, Krishnaveni and Shahin (2022) highlight how traditional games encourage cooperative play, improve interpersonal skills, and reinforce cultural traditions in early childhood education. Research highlights the importance of music, particularly through singing and structured play, in enhancing socio-emotional competencies (SEC) in preschool children. Berk (2009) discusses

how structured play, including musical activities, helps children develop emotional intelligence and social skills such as cooperation, turn-taking, and empathy. Structured musical games promote peer interactions and teach basic life skills in a fun and engaging way. Music helps in developing social skills such as sharing, cooperation, and turn-taking. In light of this, research was conducted to examine the connection between the inclusion of traditional music in activities with children and the formation and development of their socio-emotional competencies. Given the extensive research material, this paper presents results that respond to the question of how preschool teachers in the Republic of Serbia — especially in relation to age, experience, and regional affiliation — evaluate the significance of including traditional music in developing children's SEC.

Methodology

Research Goal

The main goal of this research is to examine the role of traditional music in fostering the socio-emotional development of preschool children, as perceived by preschool teachers. The study will explore how traditional music is integrated into preschool activities and its perceived impact on children's social skills, emotional intelligence, and cultural awareness.

Research Tasks

To achieve the main goal of this research, the following specific tasks have been defined:

1. Examine the frequency and methods preschool educators use to incorporate traditional music into their teaching practices.
2. Analyze preschool educators' perceptions regarding the impact of traditional music on children's socio-emotional competencies.
3. Identify challenges and barriers that may hinder the integration of traditional music into preschool education.

Hypothesis

The following hypotheses were formulated based on the main tasks and goals, which aim to explore the role of traditional music in promoting socio-emotional development in preschool children.

- H_0: Preschool teachers perceive that the inclusion of traditional music in preschool education has no significant impact on children's socio-emotional development.
- H_1: There are significant differences in the preschool teachers' perception of the impact of traditional music on the socio-emotional development of preschool children, depending on the frequency of its application in preschool education.
- H_2: There are no significant differences in the preschool teachers' perception of the impact of traditional music on preschool children's socio-emotional competencies based on their years of work experience.
- H_3: There are no significant differences in the preschool teachers' perceptions of the impact of traditional music on children's socio-emotional competencies based on their geographic location (urban vs. rural area).
- H_4: There are no significant differences in preschool teachers' perceptions of the impact of traditional music on children's socio-emotional development based on their age.
- H_5: Preschool teachers from different geographical regions of Serbia have varying opinions on the role of traditional music in children's socio-emotional development.

Data Collection and Research Procedure

The research was conducted during December 2022, employing a quantitative methodology. Data were collected through the distribution of an online questionnaire, which was shared with preschool teach-

ers across Serbia. Participation in the research was voluntary and anonymous. The questionnaire was designed to gather educators' insights into the use of traditional music in preschool settings and its perceived impact on children's socio-emotional development.

Data Collection Procedure. The online questionnaire was distributed to various educational institutions throughout Serbia, aiming to capture a diverse sample of preschool educators from different geographic regions. The survey was anonymous to ensure confidentiality and to encourage honest responses from participants.

Research Instrument. The primary research instrument for data collection was a structured online questionnaire, which was designed to capture educators' practice and perceptions on the integration of traditional music into preschool activities and its impact on children's socio–emotional development. The questionnaire consisted of several sections:

- Demographic Information: This section gathered basic demographic data from participants, including their age, gender, years of teaching experience, and geographical location.
- Use of Traditional Music: This section focused on the frequency and methods by which educators incorporate traditional music into their teaching practice. It aimed to assess the extent to which traditional music is integrated into daily preschool activities.
- Perceived Impact on Children: In this section, educators were asked to share their perceptions regarding the influence of traditional music on children's cooperation, empathy, self-expression, and cultural identity.
- Challenges and Barriers: This section explored any difficulties that educators might face in integrating traditional music into the preschool curricula.
- The questionnaire was designed based on previous studies in early childhood education and music's role in socio-emotional learning, ensuring content validity. The research instrument consists of the Social-Emotional Competence Scale for Students (Jeremić et al., 2015), which was adapted for the purpose of this study. This scale includes 21 items (Table 1) that measure the level of agreement, using a five-point Likert scale, with statements regarding the impact of traditional music on the development of social-emotional competencies (SEC) in children. The statements in the scale are grouped into three thematic areas:

Social competencies:

- Cooperation and support through peer interaction: group singing and music making;
- Prosocial behavior: especially towards marginalized children and those with developmental difficulties;
- Building friendships and accepting differences;
- Learning outside of institutional contexts;

Emotional competencies:

- Development of empathy and responsibility: helping others and openly expressing emotions;
- Strengthening self-confidence and self-respect: activities encouraging the expression of opinions and overcoming the fear of public performances;
- Reducing conflicts and negative emotions (anger, frustration, competition situations, etc.);

Practical application:

- Traditional music as a bridge to intercultural learning.

Data Analysis

Collected data were analysed using descriptive and inferential statistical methods. First, descriptive statistics (means, standard deviations, and frequencies) were used to summarize the participants' responses. To test the research hypotheses, the Kruskal-Wallis test was conducted to examine differences between groups, and the Mann-Whitney U test was used for pairwise comparisons. The data obtained through the research were analyzed using the IBM SPSS for Windows statistical package, version 20.0.

Sample Description

The study was conducted on a sample of 88 preschool teachers from preschool institutions in the Republic of Serbia. The sample predominantly consists of female participants (81 women and 7 men). Regarding geographical distribution, 53% of participants are from urban areas, while 39.8% reside in rural areas (Figure 1).

The participants' ages from 22 to 60 years, with an average age of M = 41.34 years and a standard deviation of SD = 9.290. The distribution by age categories is as follows:

- 11 participants (12.6%) are younger than 29 years,
- 22 participants (25.3%) are between 30 and 38 years old,
- 25 participants (28.7%) are between 39 and 45 years old,
- 29 participants (33.3%) are 46 years or older.

This sample structure ensures a diverse representation of preschool teachers from different age groups as well as from various geographical regions of Serbia.

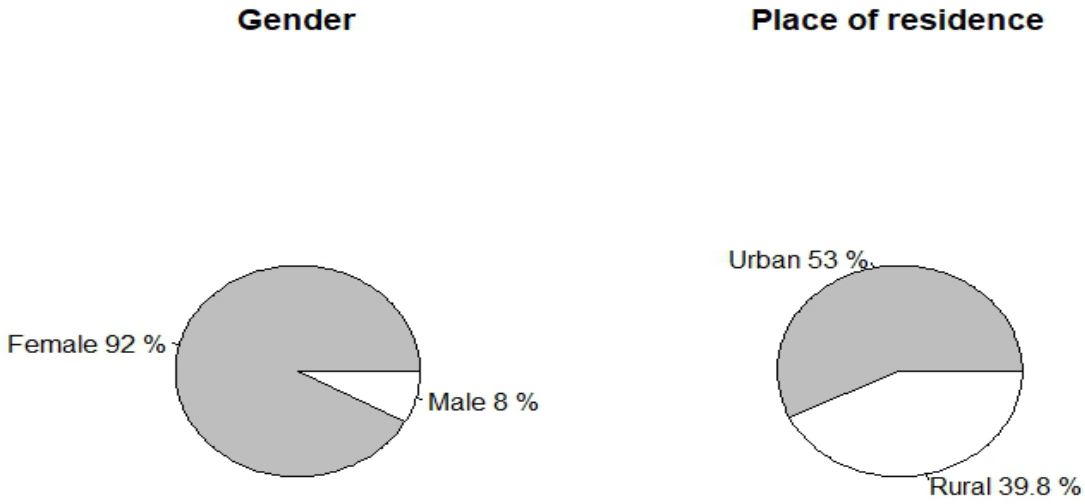

Figure 1. Sample structure by gender and place of residence

The participants' professional experience varies significantly. The average number of years in the profession is M = 14.659, with a standard deviation of SD = 8.7869. The experience levels are categorized as follows: 10 participants (11.4%) have up to three years of work experience, 20 participants (22.7%) have between three and ten years of experience, 34 participants (38.6%) have between eleven and eighteen years of experience, and 24 participants (27.3%) have more than eighteen years of experience.

In terms of regional distribution, the majority of participants are from Vojvodina (67 participants, 76.1%), followed by Belgrade (15 participants, 17%), Šumadija and Western Serbia (5 participants, 5.7%), and Southern and Eastern Serbia (1 participant, 1.1%).

The reliability of the SEC scale used in this study was assessed using Cronbach's alpha coefficient, which indicated excellent internal consistency (α = .978). The assumption of normal distribution for the SEC scale scores was tested using the Kolmogorov-Smirnov test (p = .000), which confirmed that the data do not follow a normal distribution. Consequently, non-parametric statistical methods were employed for data analysis.

Results

In the sample, 54 (61.4%) respondents report that they often apply traditional music in their educational work in preschool, 29 (33%) respondents report that they rarely apply traditional music, and 5 (5.7%) respondents indicate that they sometimes apply traditional music in their educational work.

The possible range of scores on the SEC scale is from 21 to 105. The obtained scores range from 21 to 105, with a mean value of M = 75.8182 and a standard deviation of SD = 22.34553. The weighted mean is M = 3.6104 with a standard deviation of SD = 1.06407. Based on the presented results, we can conclude that the respondents generally agree (agree) on the social-emotional competencies of preschool children. The coefficient of variation CV = 29.47 indicates that the respondents' views are homogeneous.

Table 1. *Distribution and Descriptive Measures of Respondents' Answers on the Social-Emotional Competencies of Preschool Children*

Item	f					M	SD	C_v
	1	2	3	4	5			
SEC1	5 (5.7%)	7 (8.0%)	19 (21.6%)	21 (23.9%)	36 (40.9%)	3.86	1.205	31.21
SEC2	8 (9.1%)	9 (10.2%)	22 (25.0%)	23 (26.1%)	26 (29.5%)	3.57	1.267	35.49
SEC3	5 (5.7%)	10 (11.4%)	17 (19.3%)	14 (15.9%)	42 (47.7%)	3.89	1.281	32.93
SEC4	11 (12.5%)	9 (10.2%)	16 (18.2%)	29 (33.0%)	23 (26.1%)	3.50	1.322	37.77
SEC5	5 (5.7%)	8 (9.1%)	17 (19.3%)	30 (34.1%)	28 (31.8%)	3.77	1.162	30.82
SEC6	6 (6.8%)	13 (14.8%)	21 (23.9%)	24 (27.3%)	24 (27.3%)	3.53	1.231	34.87
SEC7	7 (8.0%)	7 (8.0%)	19 (21.6%)	19 (21.6%)	36 (40.9%)	3.80	1.279	33.66
SEC8	19 (21.6%)	7 (8.0%)	23 (26.1%)	22 (25.0%)	17 (19.3%)	3.13	1.405	44.84
SEC9	15 (17.0%)	7 (8.0%)	17 (19.3%)	16 (18.2%)	33 (37.5%)	3.51	1.486	42.33
SEC10	9 (10.2%)	6 (6.8%)	17 (19.3%)	19 (21.6%)	37 (42.0%)	3.78	1.334	35.29
SEC11	5 (5.7%)	3 (3.4%)	14 (15.9%)	20 (22.7%)	46 (52.9%)	4.13	1.153	27.92
SEC12	5 (5.7%)	5 (5.7%)	12 (13.6%)	16 (18.2%)	50 (56.8%)	4.15	1.199	28.89
SEC13	11 (12.5%)	6 (6.8%)	29 (33%)	21 (23.9%)	21 (23.9%)	3.40	1.273	37.44
SEC14	6 (6.8%)	9 (10.2%)	20 (22.7%)	28 (31.8%)	25 (28.4%)	3.65	1.194	32.71
SEC15	8 (9.1%)	8 (9.1%)	19 (21.6%)	23 (26.1%)	30 (34.1%)	3.67	1.284	34.97
SEC16	14 (15.8%)	7 (8.0%)	25 (28.4%)	25 (28.4%)	17 (19.3%)	3.27	1.311	40.09
SEC17	16 (18.2%)	7 (8.0%)	28 (31.8%)	26 (29.5%)	14 (12.5%)	3.10	1.269	40.94
SEC18	11 (12.5%)	10 (11.4%)	20 (22.7%)	27 (30.7%)	20 (22.7%)	3.40	1.300	38.24
SEC19	5 (5.7%)	12 (13.6%)	17 (19.3%)	19 (21.6%)	35 (39.8%)	3.76	1.268	33.72
SEC20	8 (9.1%)	9 (10.2%)	18 (20.5%)	28 (31.8%)	25 (28.4%)	3.60	1.255	34.86
SEC21	16 (18.2%)	7 (8.0%)	18 (20.5%)	24 (27.3%)	23 (26.1%)	3.35	1.423	42.48

The data (Table 1) show that the respondents agree with the statements SEC1 – SEC7, SEC9 – SEC12, SEC14 – SEC15, and SEC19 – SEC20. The coefficients of variation indicate that the sample of educators is homogeneous when it comes to agreement with statements SEK11 and SEK12.

The Kruskal-Wallis test did not reveal a statistically significant difference in the results on the SEC scale across the four age groups (Group 1 N = 11, ≤29 years; Group 2 N = 22, 30–38 years; Group 3 N = 25, 39–45 years; Group 4 N = 29, 46 years and older), c3 (3, N = 87) = 3.108, p = .375. The age group (29 years and younger) has the highest median result Md = 88, the age group from 30 to 38 years has a median result Md = 83, the age group from 39 to 45 years has a median result Md = 72, and the age group 46 years and older has a median result Md = 83.

The Kruskal-Wallis test did not reveal a statistically significant difference in the results on the SEC scale based on the years of experience of educators, divided into four groups (Group 1 N = 10, ≤3 years of experience; Group 2 N = 20, more than 3 but less than 11 years of experience; Group 3 N = 34, 11 to 18 years of experience; Group 4 N = 24, more than 18 years of experience), c3 (3, N = 88) = 3.278, p = .351. The group with the least work experience (3 years or fewer) has a median result Md = 83.5, the

group with more than 3 but fewer than 11 years of experience has a median result Md = 77.5, the group with 11 to 18 years of experience has a median result Md = 78.5, and the group with 18 or more years of experience has the highest median result Md = 85.

The Mann-Whitney U test did not reveal a statistically significant difference in the assessment of preschool educators' SEC based on the educators' place of residence, U = 774.000, z = -1.309, p = .190. Educators residing in urban areas (N = 53) have a median result Md = 85, while educators residing in rural areas (N = 35) have a median result Md = 79.

The Kruskal-Wallis test revealed a statistically significant difference in the results on the SEC scale based on the frequency of applying traditional musical content in preschool activities, c2 (2, N = 88) = 11.041, p = .004. Educators who frequently apply traditional content in preschool activities have a median result Md = 86.5, educators who rarely apply traditional content in preschool activities have a median result Md = 69, while educators who occasionally apply traditional content in preschool activities have a median result Md = 76.

The Kruskal-Wallis test revealed a statistically significant difference in the results on the SEC scale based on the region, c2 (3, N = 88) = 9.352, p = .025. Educators working in preschools in Vojvodina have a median result Md = 83, educators working in preschools in Belgrade have a median result Md = 62, educators working in preschools in Šumadija and Western Serbia have a median result Md = 89, while educators working in preschools in Southern and Eastern Serbia have a median result Md = 82.

Discussion

The results of the research highlight the significant role of traditional music in preschool education and its impact on the socio-emotional competencies (SEC) of children. The majority of respondents (61.4%) frequently use traditional music in their work with children, indicating its perceived value in the educational process. On the other hand, a significant percentage of educators (33%) rarely use this type of content, which potentially points to the need for additional education or the creation of more stimulating conditions for the application of traditional music.

The research further demonstrates that frequent use of traditional music is associated with higher levels of SEC in children, thereby reinforcing the findings of international studies which show a positive link between music education and the development of cooperation, empathy, and self-regulation (Koelsch, 2014; Marsh, 2010). Research undertaken in Australia and the United States also highlights that structured music programmes enhance children's emotional intelligence and social skills, particularly in early childhood settings (Custodero, 2005; Koops, 2014). These findings suggest that while traditional music is acknowledged as an important educational tool, its use is not universal across all preschools. The variation in the frequency of its application might reflect a lack of awareness about its benefits or insufficient resources to integrate it into the daily routine. Therefore, further training for educators, as well as the development of supportive environments that encourage the inclusion of traditional music, could help maximize its educational potential. Given that traditional music was found to have a significant impact on the socio-emotional development of children, H_0: *Preschool teachers perceive that the inclusion of traditional music in preschool education has no significant impact on children's socio-emotional development* is rejected.

Moreover, the research demonstrates that frequent use of traditional music is associated with higher levels of SEC in children. This reinforces the idea that music, particularly traditional forms, is not only an aesthetic experience but also a tool for fostering social and emotional skills such as empathy, cooperation, and self-esteem. These skills are vital for the overall development of preschool-aged children, as they lay the foundation for positive social interactions and emotional well-being later in life.

The analysis of the results on the SEC scale showed homogeneity in the attitudes of the educators, with an average value of 75.8182 (SD = 22.34553). This result indicates general agreement among the educators regarding the importance of developing SEC in preschool children. The presence of high median values in the groups that frequently use traditional music (Md = 86.5) further confirms the positive impact of traditional music content on the socio-emotional development of children.

Furthermore, the Kruskal-Wallis test revealed significant differences in SEC levels based on the frequency of traditional music's incorporation in preschool activities (p = .004). This finding aligns with the observations reported by Krishnaveni and Shahin (2022), who documented that musical activities

have a substantial impact on enhancing children's social behaviour, particularly in cultivating prosocial interactions and mitigating conflicts. Thus, H_1: *There are significant differences in the preschool teachers' perception of the impact of traditional music on the socio-emotional development of preschool children, depending on the frequency of its application in preschool* education is confirmed.

The data suggest that it is necessary to intensify the use of traditional music as a tool for the development of SEC in all preschool institutions. Additionally, music encourages self-regulation, a key aspect of emotional development. Although the specific impact of traditional music on socio-emotional development has not always been explicitly studied, it is reasonable to assume that traditional music can amplify these effects. Traditional music, which is often shared in cultural or family contexts, provides a meaningful framework for practicing these skills. The knowledge and cultural relevance of traditional songs and games further engage children emotionally and socially. These findings align with research showing that music, particularly with local and traditional elements, fosters emotional intelligence, empathy, and social skills in children (Barrett, 2011; Hallam, 2010; Koelsch, 2014).

Additionally, the data suggest that there were no significant differences in preschool teachers' perceptions of the impact of traditional music on SEC based on their years of work experience or their age, indicating that these factors do not influence how educators perceive the role of traditional music in children's development. As a result, H_2: *There are no significant differences in the preschool teachers' perception of the impact of traditional music on preschool children's socio-emotional competencies based on their years of work experience* and H_4: *There are no significant differences in preschool teachers' perceptions of the impact of traditional music on children's socio-emotional development based on their age* are confirmed.

The results of the Mann-Whitney U test indicate the absence of statistically significant differences in relation to the educators' place of residence, suggesting the potential universality of these findings across different environments. However, regional differences emphasize the need for tailored approaches in working with children, depending on the local culture and tradition (Vukićević, Golubović Ilić, and Stanojević, 2016). This leads to the confirmation of H_3: *There are no significant differences in the preschool teachers' perceptions of the impact of traditional music on children's socio-emotional competencies based on their geographic location*.

Notwithstanding the demonstrable benefits, the data indicate significant heterogeneity in the implementation of traditional music across diverse regions within Serbia. This phenomenon of regional variation has been observed in studies conducted in Indonesia and Spain, where cultural differences have been shown to influence the extent to which traditional music is embedded in early childhood education (Ashar et al., 2024; Good, 2021). This finding indicates that, while traditional music is a universal medium for socio-emotional development, its implementation is contingent on contextual factors, including educational policies and cultural traditions. The significance of traditional music as a didactic tool lies not only in its cultural aspect but also in its ability to stimulate the cognitive, emotional, and social development of children. Since the findings indicate variability in teachers' perceptions based on their geographical region, H_5: *Preschool teachers from different geographical regions of Serbia have varying opinions on the role of traditional music in children's socio-emotional development* is confirmed. These findings highlight the need to improve curricula and provide additional resources for educators in order to optimize the use of traditional music in early childhood education. Socio-cultural activities like drama, sports, dance and folk arts along with traditional games as group participatory events enhances effective communicative abilities, community belonging, interpersonal competence (Krishnaveni and Shahin, 2022).

In conclusion, the results suggest that traditional music plays an essential role in shaping the socio-emotional competencies of young children, and its more consistent application in preschool settings could further enhance these benefits. Future research could explore how specific types of traditional music influence different aspects of socio-emotional development and whether educators' attitudes toward traditional music differ across regions and educational contexts.

Conclusion

This study provides empirical evidence that traditional music significantly contributes to the development of socio-emotional competencies (SEC) in preschool children. The majority of educators participating in this research frequently incorporate traditional music into their teaching practices, recognising

its potential as an educational tool. The study confirms that traditional music supports the development of creativity, empathy, and communication skills while fostering cultural appreciation (Ginsburg, 2007; Hallam, 2010; Pica, 2011).

A salient finding of this study is that educators who consistently integrate traditional music into preschool activities report higher SEC levels among children. This finding suggests that structured exposure to traditional music enhances emotional intelligence, social integration, and self-expression in early childhood. The study also revealed that while no statistically significant differences were observed based on educators' age, experience, or place of residence, regional variations indicate the need for a more localised and culturally responsive approach to implementing traditional music in preschool education. These findings are consistent with those of previous studies that have underscored the significance of music in cognitive, social, and emotional development. (Koelsch, 2014). Traditional music represents not only a means of transmitting cultural heritage but also a bridge between the past and the future, helping children develop their personal and cultural identity. This music can be a powerful tool for fostering empathy, increasing interest in historical topics, and motivating students during lessons (Trbojević, Jeremić, and Milenović, 2015).

Whilst the present study provides valuable insights into the role of traditional music in early childhood education, it is important to note that it is not without certain limitations. Firstly, the research was conducted within a specific geographical and cultural context, which may affect the generalisability of the findings. Secondly, the study is dependent on educators' perceptions, as opposed to direct observations or assessments of children's responses to traditional music activities. To address these limitations, future research should: Conducting longitudinal studies to examine the long-term effects of traditional music on socio-emotional development. Furthermore, expanding the scope of research to encompass direct observations of children's engagement and development in response to traditional music could provide more comprehensive insights. A further recommendation is to compare the effects of traditional music with those of other music genres, in order to ascertain its unique contributions to socio-emotional growth. Finally, exploring the role of digital resources in preserving and integrating traditional music into early childhood education would be a valuable avenue for future research. Given the findings of this study, it is recommended that traditional music be strategically and innovatively incorporated into educational programs. This includes training educators, developing appropriate teaching materials, and promoting an interdisciplinary approach (Trbojević, Jeremić, and Milenović, 2015). In an era of globalisation and the universalisation of cultural values, preserving and nurturing traditional music is not only a cultural task but also a crucial contribution to building a more humane and socially integrated society.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, Jeremić, B., Trbojević, A. and Tubić, M.; methodology, Goridić, S. and Trbojević, A.; formal analysis, Jović Vujaković, F. and Vojvodić Savić, M.; writing—original draft preparation, Jeremić, B., Tubić, M., Vojvodić Savić, M. and Jović Vujaković, F.; writing—review and editing, Jeremić, B., Trbojević, A., Vojvodić Savić, M. and Goridić, S. All authors have read and agreed to the published version of the manuscript.

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Research Trends in Scopus Database on Technological Innovation in the Process of Mathematics Learning: A Bibliometric Analysis

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Abstract: The purpose of this analysis is to look at publication trends in research on technological innovation in the process of mathematics learning analyzed by bibliometric analysis. Using predetermined keywords, the authors analyzed 262 documents that had been selected by the PRISMA method, with the next step being bibliometric analysis with the R Program and VOSviewer. From the analysis, research on technological innovation in mathematics learning started in 1987 and showed significant growth until 2024, with a clear surge in publications since 2010 and a peak in 2023. The United States and Australia lead the way in the number of publications and citations, demonstrating their great influence in this field. Universiti Putra Malaysia, along with leading universities in Australia and South Africa, show dominance in publications related to this topic. Journals in the Q1 category play a major role in advancing knowledge about technology in mathematics education, In the keyword grouping, new trends are emerging such as the use of technologies like “Artificial Intelligence” and “Blended Learning” which are becoming new directions in technological innovation in the process of mathematics learning.

Keywords: *technology, mathematics learning, bibliometric.*

Introduction

The development of education after war has undergone a significant transformation, with many countries seeking to rebuild their education systems to support social and economic recovery (Ma et al., 2022). Education serves not only as a tool to disseminate knowledge, but also as a means to shape character and prepare young people for future challenges (Behnamnia et al., 2020; González-Pérez and Ramírez-Montoya, 2022; Izzulhaq et al., 2024). The existence of inclusive and quality education is becoming increasingly important in a global context, where access to education can help reduce social inequalities and improve people’s well-being. By utilizing technology and innovative teaching methods, education can reach more students, including those in remote areas (Munoz-Najar et al., 2021). Thus, the importance of schools as institutions that provide quality education cannot be ignored, as they serve as the main foundation in creating a smart and competitive society.

School is a vital place for children’s intellectual and social development, where they learn various skills necessary for the future (Akour and Alenezi, 2022; Alam and Mohanty, 2023b). Schools not only provide formal education, but also shape character and values that are important in life (Dunne, 2021). Access to quality schools is essential to ensure that all children, regardless of their background, have equal

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opportunities to learn and grow (Alam and Mohanty, 2023a). However, there are still many challenges faced, such as limited facilities and resources that can affect students' learning experience. Therefore, attention to school conditions is crucial, as a good and supportive environment will have a direct effect on student motivation and success (Alemayehu and Chen, 2023). Thus, it is important to understand that optimal classroom conditions are instrumental in creating an effective learning atmosphere.

The classroom is a space that greatly influences children's academic and social development (Piipponen et al., 2024). In the classroom, they not only learn subject matter, but also develop social skills, such as communicating and cooperating with their peers (Kim et al., 2022; Saleem et al., 2024). These children's development is highly dependent on a supportive environment, so the condition of the classroom is a factor that cannot be ignored (Miller-Cotto et al., 2022). The school's attention to the comfort and completeness of classroom facilities is an important part of creating a conducive learning atmosphere (Feng et al., 2024). Classroom conditions should be designed in such a way as to inspire students to learn more vigorously and feel comfortable while being in it (Dai, 2021; Hsieh et al., 2020). With sufficient lighting, good ventilation and adequate equipment, the classroom will be an optimal place for student development. Therefore, attention to classroom conditions should not only focus on the physical space, but also how it supports the learning process and student motivation (Rusticus et al., 2023). This attention will go a long way in improving the quality of learning in schools.

Learning is a very important process in shaping students' intellectual, emotional, and social abilities (Gueldner et al., 2020). The important part of this education is how students can understand the material and apply it in everyday life (Chew and Cerbin, 2021). The effective learning process requires innovative and adaptive methods, so that students can more easily understand the various concepts taught (Morze et al., 2021). In creating a conducive learning atmosphere, teachers play a big role in choosing an approach that suits the needs of students. The supportive environment and active involvement of students will increase the effectiveness of the learning process (Raza et al., 2023; Sökmen, 2021). With the development of the times, many learning methods began to adapt to cover a variety of approaches, one of which is with technology that is increasingly integrated in the education system.

Technology is a very important tool in education, as it can enrich students' learning experience in many ways (Arulanand et al., 2020; Ruiz-Rojas et al., 2023; Sofi-Karim et al., 2023). It can help students to access information more quickly and efficiently, and allow them to learn in an interactive and practical way. Students can utilize technology to deepen their understanding through various educational apps, learning videos and other online resources (Sofi-Karim et al., 2023). In addition, technology can also provide simulations and visual tools that make it easier for students to understand complex concepts (Yıldırım et al., 2020). By optimally utilizing technology, students can learn in a way that is more engaging and suits their individual learning styles (Alam, 2023; Cabual, 2021). Therefore, the appropriate use of technology can be beneficial in improving the effectiveness of mathematics learning, by providing a more dynamic and comprehensible experience.

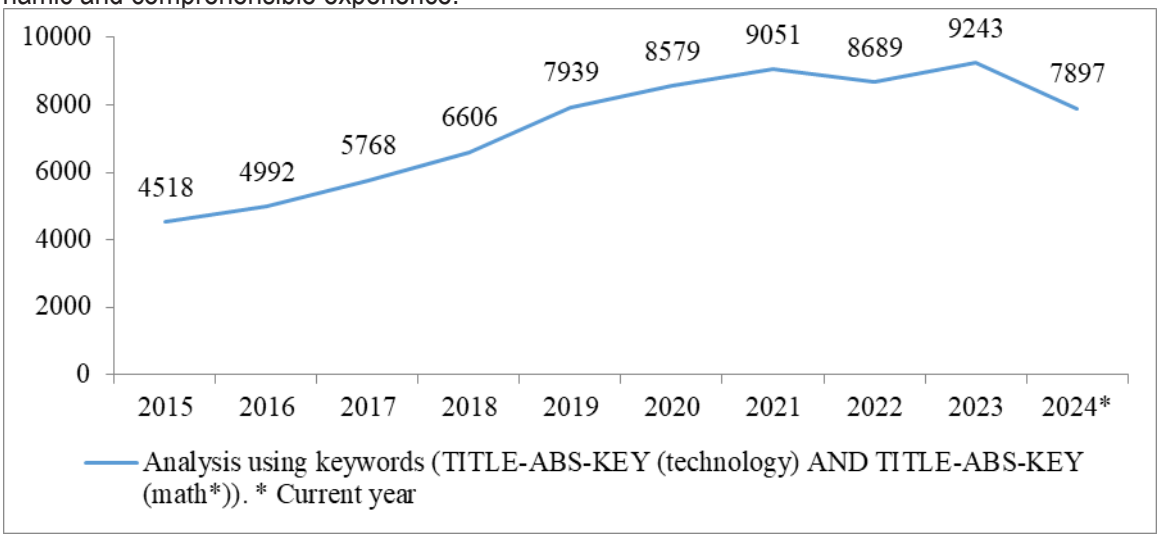

Figure 1. Trends Discussing Technology in Mathematics in the Scopus Database (Data retrieved on November 6, 2024)

Discussions on the use of technology in mathematics in general are increasingly discussed in various publications recorded in the Scopus database. As shown in Figure 1, the data shows a positive trend in the number of publications that generally address the topic of technology in mathematics from 2015 to 2021, with a consistent increase each year. This increase indicates the growing interest and attention of researchers in the application of technology in mathematics education, which continues to evolve with technological advances and the need for digital learning. However, in 2022, this trend experienced a significant decline, where the number of publications decreased from 9051 to 8689, which may reflect various challenges faced in technology research in mathematics education or a temporary decline in research interest. Nonetheless, the number of publications again showed an increase in 2023, suggesting that this topic remains relevant and attracts the attention of the academic community. Overall, these publication trends indicate a consistent and sustained interest in the topic of technology in mathematics, despite some fluctuations in the middle of the period studied, underscoring the importance of this topic in the modern educational domain.

Analysis of previous publications showed that the use of ICT in mathematics learning has increased significantly, especially in terms of ease of understanding and teaching effectiveness. The first study found an increasing trend of publications addressing ICT in mathematics since 2017, with a peak in 2019, and three main themes (Julianis, 2023). However, this study only focused on analyzing publication trends without looking at the contribution of inter-researcher collaboration or inter-institutional linkages. Meanwhile, the second study highlighted that while there are many publications addressing ICT in mathematics education, most of the current research tends to be published in sources with a low citation index and shows a lack of strong research collaboration, especially among international institutions (Trinh Thi Phuong et al., 2022). The shortcomings of these two studies suggest that while ICT in mathematics learning has been widely researched, there are still aspects that require updating, especially in optimizing international collaborations and exploring new themes that can enhance innovation in this area.

From the introduction and findings presented, the authors conclude that while the use of technology in mathematics learning has shown a positive trend in publications over the years, there are some challenges that need to be addressed, such as the sharp decline in the number of publications by 2022 and the low citation index of most recent publications. Although this topic continues to attract attention, the lack of inter-researcher and inter-institutional research collaboration, especially at the international level, is one of the shortcomings that need to be corrected. Therefore, there is a need for renewal in research on technology in mathematics learning, with a focus on optimizing international collaboration and exploring new themes that can drive innovation in mathematics education. So, the research questions can be described as follows:

RQ1. What is the main information, publication trends from year to year, collaborating and most productive countries, collaborating and most productive affiliates, most productive researchers, most productive sources, and documents with the highest citations on the topic on technological innovation in the Process in mathematics learning?

RQ2. How to group keywords and novelty keywords that can be recommended for conducting further research in the field on technological innovation in the Process in mathematics learning?

Materials and Methods

Research Design

This research is a bibliometric analysis on Technological Innovation in the Process mathematics learning. Bibliometrics is a method used to analyze scientific publications, including writing trends, citations, and collaboration between researchers in a particular field (Moral-muñoz et al., 2020; Tomaszewski, 2023). Through this approach, research developments can be mapped, emerging topics identified, as well as contributions from various countries and institutions to the topics discussed. In the context of technological innovation, bibliometrics can help to identify the latest applications of technology in mathematics learning and understand the extent to which this topic has received attention in the scientific literature. Thus, bibliometric analysis not only provides an overview of research trends, but also opens up opportunities for further innovation in the processes of the field of mathematics education.

Search Strategy

In searching for documents in the Scopus Database, the author uses the keywords "(TITLE (technology) AND TITLE (math*) AND TITLE (educat*) OR TITLE (learn*) AND NOT TITLE-ABS-KEY (stem) AND NOT TITLE-ABS- KEY (steam))". The author limits keywords by not involving the words STEM and STEAM. This is because the focus of this research is more emphasis on the use of technology in mathematics learning in general, without involving specific aspects related to science, technology, engineering and mathematics which are usually covered by the concept of STEM or STEAM. By avoiding these keywords, the author can ensure that the documents found are more relevant to the topic on technological innovation in the foundations and process in mathematics learning, without overlapping with broader topics regarding the overall discussion of STEM.

Data searches were carried out using the Scopus database, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology for document selection. This approach aims to provide a systematic and transparent document selection process, so that only truly relevant and high-quality articles are included in the analysis. By using PRISMA, the author can ensure that all steps for searching and selecting articles are carried out in a clear and structured manner (Page et al., 2021; Rethlefsen et al., 2021). So that the results of this research can be justified and provide an accurate picture of technological trends on process in mathematics learning.

Inclusion and Exclusion Criteria

At the Identification stage, the author entered keywords according to the provisions explained in the "Search Strategy" section, resulting in 751 initial documents. This stage aims to filter all documents that are potentially relevant to the topic of "Technological Innovation in the Process of Mathematics Learning", allowing for a more in-depth analysis. The selected keywords were designed to cover the main topic without including terms that could broaden the scope too much, such as "STEM" and "STEAM". The exclusion of "STEM" and "STEAM" terms was made to ensure that the obtained documents specifically focus on the application of technology in mathematics learning without expanding into broader educational contexts. In this way, the author hopes to gather articles that genuinely concentrate on the use of technology in the mathematics learning process.

At the Screening stage, researchers focused on the subject areas of "Social Sciences", "Computer Sciences", and "Mathematics", selected based on their relevance to technological innovation in mathematics education. These three fields encompass pedagogical aspects, technological advancements, and the application of mathematical concepts in digital environments. Documents classified as "Articles" were chosen because journal articles generally undergo a rigorous peer-review process, ensuring the validity and quality of the analyzed information. This selection successfully eliminated 428 unsuitable documents, leaving 323 for further analysis. At the Inclusion stage, the author conducted a manual review by examining the titles and abstracts to ensure each document was truly relevant to the research topic and did not include discussions that were too broad or unrelated. Inappropriate documents were eliminated, reducing the total by 61, leaving 262 documents ready for bibliometric analysis at this stage.

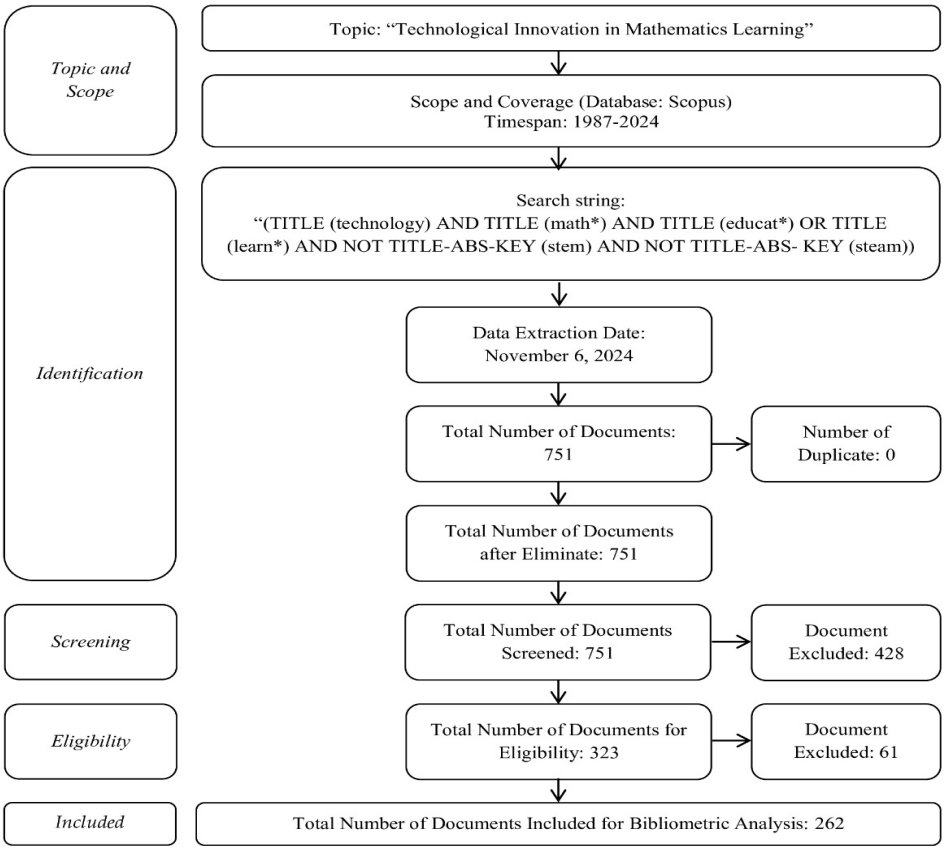

Figure 2. Document Selection Using the PRISMA Method. Flowchart by Page et al, (2021)

Data Analyze

After selecting documents and obtaining 262 final documents, the author continued with bibliometric analysis using VOSviewer software and the R program. With this method, the author was able to explore and compile a visual map of existing literature, thereby providing a comprehensive picture of research developments. This analysis begins by interpreting the first Research Question (RQ1), which includes main information, publication trends from year to year, as well as collaborating and most productive countries. Apart from that, the author also identified the most productive institutions and authors, as well as publication sources that produce the most documents in this field, to documents that have the highest number of citations. These steps aim to gain an in-depth understanding of the contribution and distribution of research related to technology in mathematics learning.

Next, the author interprets the second Research Question (RQ2) which focuses on group keywords and novelty keywords. This analysis is carried out to identify the main themes that emerge in the research, as well as innovations or new topics that may become trends in the future. By mapping these keywords, authors can understand how research focus changes and develops, as well as discover potential research areas that have not been widely explored. This keyword analysis also helped to uncover new aspects of technological innovation in the foundations and processes of mathematics learning, which could form the basis for further research or the development of more innovative methodologies in this area.

Results

The author answers RQ1 by presenting the results regarding main information, publication trends from year to year, as well as collaborating and most productive countries. Apart from that, the author also identified the most productive institutions and researchers, as well as publication sources that produce the most documents in this field, and documents that have the highest number of citations. These results were analyzed by using the R Program.

Main Information

In Figure 3, it can be seen that research on technological innovation in the process of mathematics learning began in 1987 and continues until 2024, with a total of 262 documents published. The average annual growth of publications in this field was 9.09%, indicating a consistent increase over time. A total of 153 reference sources were used as references, involving 644 authors. Of these authors, 53 of them are sole authors, while the level of international collaboration reached 16.41%, which indicates the existence of a global collaboration network in this research. The average number of authors per document was 2.71, indicating that most research was conducted collaboratively. The number of keywords used in this research is 699, which gives an idea of the variety of topics or research focuses in this field. The total references used were 9,997, showing the depth of the literature on which this research is based. The average age of the documents or research referred to is 8.47 years, indicating that the research still refers to relatively recent literature. Finally, each document in this field received an average of 11.61 citations, reflecting the level of influence or significance of this research in the academic community.

Figure 3. Main Information regarding Research on Technological Innovation in the Process of Mathematics Learning in the Scopus Database (Analysis with R Program)

Publication Trends from Year to Year

Analysis of publication trends from year to year aims to understand the development and increase in research interest in technology topics in mathematics learning from time to time.

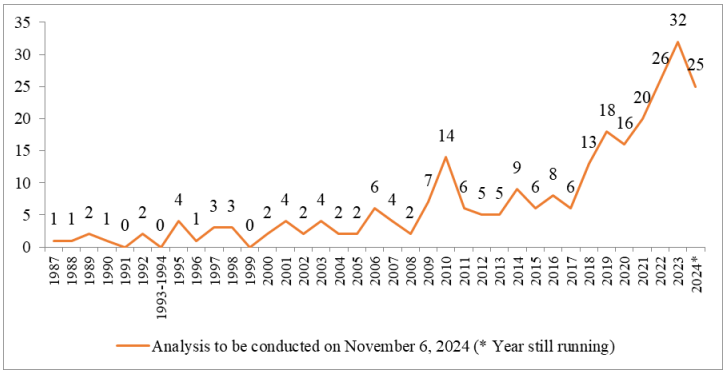

Figure 4. Number of Publications from 1987 to 2024 on the topic on Technological Innovation in the Process of Mathematics Learning (Analysis with R Program)

In Figure 3, it can be seen that there were several years or periods that recorded zero publications, namely 1991, 1993-1994, and 1999. This shows that in this period, attention to technology topics in mathematics learning was still very low, or technology had not developed enough to be widely applied in the field of mathematics education. The lack of publications in these years could also indicate that research in this area had not been a priority, so that few or even no articles were published. Furthermore, it can be seen that the growth in publications from 1987 to 2009 only produced 53 (20.22%) documents, which indicates that during that period interest and research activities on technology in mathematics learning were still limited. However, after 2010, the number of publications increased almost 4-fold, reaching 209 (79.77%) documents, with the peak publication occurring in 2023 at 32 (12.21%) publications. This shows that in the last decade, interest in research in this area has grown rapidly, along with technological advances that are increasingly being adopted in education and the increasing need for technology-based learning innovations in the basis and process of mathematics learning.

The Most Productive and Collaborative Between Countries in the World

The most productive and collaborative between countries analysis aims to identify the countries that are most active in producing publications and establishing collaborations in the field of technology research in mathematics learning.

Table 1. *The Top 10 Most Productive Countries on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Country	Continent	NP	%	TC	%
1st	United States	North America	37	14.12%	597	33.15%
2nd	Australia	Oceania	13	4.96%	566	31.43%
3rd	China	Asia	12	4.58%	117	6.50%
4th	South Africa	Africa	11	4.20%	60	3.33%
5th	Turkey	Asia	9	3.44%	73	4.05%
6th	United Kingdom	Europe	7	2.67%	100	5.55%
7th	Mexico	North America	6	2.29%	58	3.22%
8th	Canada	North America	5	1.91%	22	1.22%
9th	Kazakhstan	Asia	5	1.91%	6	0.33%
10th	Malaysia	Asia	5	1.91%	41	2.28%

Description: NP= Number of Publications, TC= Total of Citations

Based on the visualization in Figure 5, the international collaboration network shows close connections between several countries in research on technological innovation for mathematics learning. The United States is seen as the center of this collaboration network, showing great influence in research in this area. Around the USA, there are countries such as Canada, Germany and Italy which also have strong connections, forming a large group connected in a global network. On the other hand, there are also small groups such as countries in the Arab region (Saudi Arabia, Kuwait, United Arab Emirates) as well as a European group involving the UK, Finland and Cyprus, which also form a significant collaboration network. This indicates that there is cooperation between countries in strengthening research in the field of educational technology.

This collaboration network is in line with the results in Table 1, where the United States shows a dominant role in publications related to technological innovation in mathematics learning, followed by countries such as Australia, which, although having a smaller number of publications, still makes a significant contribution. North America (which includes the USA, Mexico, and Canada) and Asia (with countries such as China, Turkey, Kazakhstan, and Malaysia) are regions that are active in publications in this field. Contributions from countries on the continent highlight their high involvement in research, while countries from Africa (such as South Africa) and Oceania (Australia) show a strong impact in the global citation network despite a lower number of publications.

The Most Productive Affiliation and Collaboration Between Affiliation

Analysis of the most productive affiliates and collaboration between affiliates aims to identify the most productive affiliates in producing scientific publications. In addition, this analysis also aims to understand collaboration patterns between affiliates who contribute to research related to technological innovation in mathematics learning.

Table 2. *The Top 10 Most Productive Affiliation on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Affiliation	City	Country	NP	%
1st	Universiti Putra Malaysia	Serdang	Malaysia	9	3.44%
2nd	The University of Queensland	Brisbane	Australia	7	2.67%
3rd	University of KwaZulu-Natal	Durban	South Africa	7	2.67%
4th	University of Pretoria	Pretoria	South Africa	7	2.67%
5th	Johannes Kepler University	Linz	Austria	6	2.29%
6th	The University of Texas at Austin	Austin	United States	6	2.29%
7th	University of Vienna	Vienna	Austria	6	2.29%
8th	Arizona State University	Tempe	United States	5	1.91%
9th	Khmelnytskyi Humanitarian-Pedagogical Academy	Khmelnytskyi	Ukraine	5	1.91%
10th	National and Kapodistrian University of Athens	Athens	Greece	5	1.91%

Description: NP= Number of Publications

Based on Table 2, Universiti Putra Malaysia in Serdang, Malaysia, ranks highest with 9 (3.44%) publications, showing dominance in research related to technological innovation in mathematics learning. Followed by The University of Queensland in Brisbane, Australia, as well as two universities in South Africa, namely the University of KwaZulu-Natal in Durban and the University of Pretoria in Pretoria, each with 7 (2.67%) publications. The presence of two South African universities in the top ranking highlights Africa's significant contribution to this field, alongside the dominance of universities in Asia and Australia.

Overall, institutions from various continents, such as Asia, Africa, Europe and America an active role in this research. Austria has two influential affiliates, namely Johannes Kepler University and the University of Vienna, which demonstrate strong European contributions. Meanwhile, the United States also features productive universities such as The University of Texas at Austin and Arizona State University. Although the contribution of each affiliate in terms of number of publications varies, collectively these universities strengthen global research collaboration and development in technological innovation in mathematics education, highlighting cross-continental relevance in the development of modern educational practices.

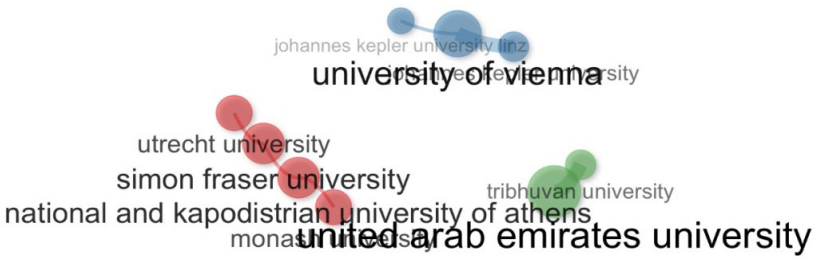

Figure 6. Visualization Results regarding Collaboration between Affiliation in the World on the topic on Technological Innovation in the Process of Mathematics Learning (Analysis with R Program)

In the results from Figure 6, it can be seen that there is a strong pattern of collaboration between universities in various countries in research on Technological Innovation in the Process of Mathematics learning. The University of Vienna, United Arab Emirates University and Simon Fraser University stand out as collaboration centers that attract other universities to work together in this field. This collaboration shows the importance of cross-country synergy in strengthening research and expanding the scope of knowledge. In addition, the involvement of various universities from various regions, such as Europe, Asia and the Middle East, reflects joint efforts to increase the effectiveness on Technological Innovation in the Foundations and Process education. By connecting these institutions, it is hoped that the resulting knowledge and innovation can be spread more quickly and adopted by various parties.

The results in Figure 6 and Table 2 both show the great contribution of a number of universities around the world in advancing research on Technological Innovation in the Process of Mathematics learning. Although Figure 6 highlights the collaborative relationships between universities, while Table 2 shows the most productive institutions based on the number of publications, both illustrate the important role of universities in various parts of the world. Universities in Asia, Africa and Australia, in particular, have shown significant contributions, both through publications and collaborations. This underlines that research in this area is not only productive, but also has a widespread impact through international cooperation.

The Most Productive Researchers

The analysis of the most productive researchers aims to identify individuals who have made major contributions to research related to technological innovation in mathematics learning, based on the impact and quality of their work. In the analysis shown in Table 3, the authors chose to use the h-index as the basis for ranking, rather than just the number of publications, in contrast to Figure 7 depicting overall researcher productivity based on the number of documents and citations. It aims to assess not only the productivity of researchers, but also how often their work is cited by the academic community, reflecting the influence and relevance of research in the field of technology-based mathematics education.

Table 3. *The Top 10 Most Productive Researcher on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Author	Affiliation	Country	h	TC	NP
1st	Goos Merrilyn	University of the Sunshine Coast	Australia	3	183(10.16%)	3(1.15%)
2nd	Graham Marien Alet	University of Pretoria	South Africa	3	24(1.33%)	4(1.53%)
3rd	Hohenwarter Markus	Johannes Kepler University Linz	Austria	3	18(1.00%)	3(1.15%)
4th	Houghton Tony	Johannes Kepler University Linz	Austria	3	18(1.00%)	3(1.15%)
5th	Kynigos Chronis	National and Kapodistrian University of Athens	Greece	3	27(1.50%)	4(1.53%)
6th	Lavicza Zsolt	Johannes Kepler University	Austria	3	20(1.11%)	4(1.53%)
7th	Mayerhofer Martin	University of Vienna	Austria	3	18(1.00%)	4(1.53%)
8th	Saal Petronella Elize	Human Sciences Research Council	South Africa	3	24(1.33%)	4(1.53%)
9th	Van Ryneveld Linda	University of Pretoria	South Africa	3	18(1.00%)	3(1.15%)
10th	Weinhandl Robert	Johannes Kepler University	Austria	3	18(1.00%)	4(1.53%)

Description: h=h-index, NP= Number of Publications, TC= Total of Citations

Based on the Table 3, the author with the highest number of publications is Goos Merrilyn from the University of the Sunshine Coast, who has 3 publications and a total of 183 citations. However, in terms of distribution of publications, dominance is seen at Johannes Kepler University Linz which has several productive authors, including Hohenwarter Markus, Houghton Tony, Lavicza Zsolt, and Weinhandl Robert, with 3 to 4 publications each. All of these authors have a consistent h-index of 3 and contribute to developing topics related to technology in mathematics learning. Johannes Kepler University's dominance in this list shows the institution's significant contribution to research in this field, both in terms of quality and quantity of publications.

In addition, a number of authors from various universities such as the University of Pretoria and the National and Kapodistrian University of Athens also contributed a no less significant number of publications, with 3 to 4 publications each. This diversity of affiliations indicates strong international collaboration in research on technological innovation in the process of mathematics learning. Overall, these authors, although coming from universities around the world, make important contributions to enriching the literature and strengthening research trends in educational technology, especially those focused on mathematics.

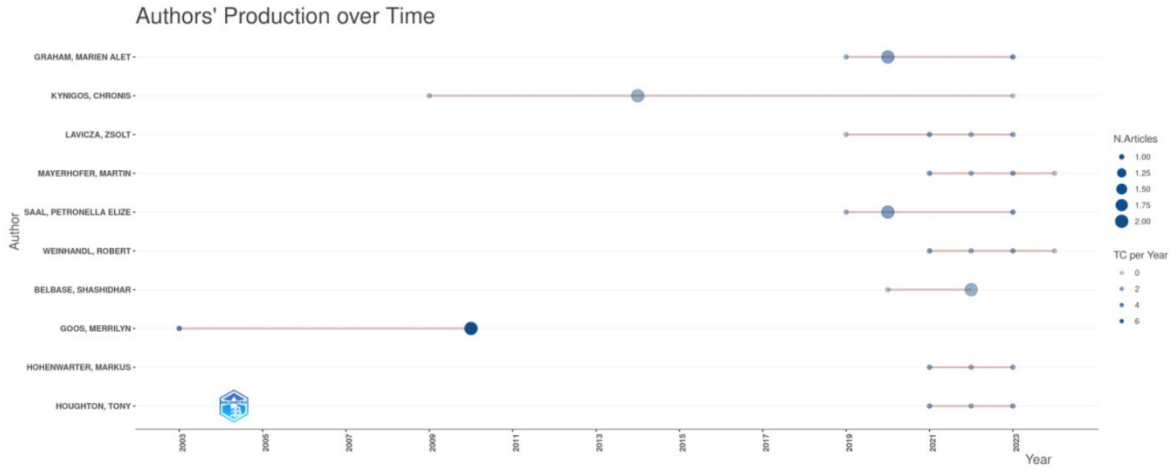

Figure 7. Visualization Results regarding Authors' Production over Time on the topic on Technological Innovation in the Process of Mathematics Learning (Analysis with R Program)

From Figure 7, it can be seen that the production of articles by writers related to research on Technological Innovation in the Process of Mathematics learning has varied over a certain period of time. Some authors, such as Kynigos Chronis and Lavicza Zsolt, show consistency in publications, with contributions spread across several years. There are also authors such as Goos Merrilyn, who have limited but significant production periods in certain years. This visualization shows how each author contributed differently over a period of time, with the size of the circles indicating the number of publications and the color intensity indicating the citation rate per year. This phenomenon indicates differences in patterns of engagement in research, which may reflect a sustained research focus or more sporadic research activities.

The relationship between Figure 7 and Table 3 shows the contribution of authors from several countries, especially from universities in Australia, South Africa and Austria, in publications and citations on the topic on Technological Innovation in the Process of learning. The top authors in Table 3, such as Goos Merrilyn from Australia and several authors from South Africa and Austria, show high contributions to this research, both in terms of publications and citations. A comparison between this figure and table shows how productive writers who have high h-index values not only actively publish but also have significant influence in this field. This linkage emphasizes the importance of the contributions of leading authors from various countries in enriching academic literature and shows the important role of international universities in encouraging collaboration and the dissemination of knowledge.

The Most Productive Source

Productive source analysis aims to identify the journals or publication sources most frequently used by researchers in a particular field. This is important to understand where innovative research in mathematics learning with technology tends to be published, as well as to assess the impact and relevance of these journals in the scientific community.

Table 4. *The Top 10 Most Productive Source on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	**Journal Name**	**SQ**	**Country[a]**	**h**	**TC**	**NP**
1st	Education and Information Technologies	Q1	United States	7	151(8.38%)	12(4.58%)
2nd	Educational Studies in Mathematics	Q1	Netherlands	6	186(10.33%)	9(3.44%)
3rd	Mathematics Education Research Journal	Q1	Netherlands	6	252(13.99%)	7(2.67%)
4th	Computers and Education	Q1	United Kingdom	5	371(20.60%)	5(1.91%)
5th	Eurasia Journal of Mathematics, Science and Technology Education	Q2	Turkey	5	82(4.55%)	7(2.67%)
6th	International Journal of Mathematical Education in Science and Technology	Q2	United Kingdom	4	63(3.50%)	8(3.05%)
7th	ZDM - Mathematics Education	Q1	Germany	4	58(3.22%)	4(1.53%)
8th	British Journal of Educational Technology	Q1	United Kingdom	3	136(7.55%)	3(1.15%)
9th	Computers in the Schools	Q2	United States	3	20(1.11%)	5(1.91%)
10th	Education Sciences	Q2	Switzerland	3	21(1.17%)	6(2.29%)

Description: SQ= Scopus Quartile, a = Country based on origin of Publisher from Source, h=h-index, NP= Number of Publications, TC= Total of Citations

The journal with the highest number of publications came from “Education and Information Technologies” with 12(4.58%) articles and total citations of 151(8.38%). Followed by “Educational Studies in Mathematics” and “Mathematics Education Research Journal”, which despite having fewer articles, showed a significant impact with total citations of 186(10.33%) and 252(13.99%) respectively. The journal with the highest citation impact was “Computers and Education” from United Kingdom, which, despite only having 5(1.91%) publications, managed to get 371(20.60%) citations. This shows that the quality of research published in these journals is highly recognized in the scientific community.

Geographically, the United Kingdom dominates with three influential journals, all of which are ranked Q1, indicating high quality in scientific publications. Q1 journals generally dominate, indicating that research on technological innovation in the process of mathematics learning is published in high-quality sources, with a total of six out of ten journals in this category. Although journals from the United States, Turkey, and Switzerland represent smaller contributions, all of these sources play a role in enriching the global literature, highlighting the importance of international collaboration in this field.

Documents with the Highest Citations

Documents with the highest citations analysis aims to identify works that have had the greatest influence in a particular field, measured by the number of citations received. By understanding these documents, it is possible to recognize their important contributions in directing research and influencing subsequent studies.

Table 5. *The Top 10 Documents with the Highest Citations on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Citation	Title	Source	SQ	TC
1st	(Pierce et al., 2007)	A scale for monitoring students' attitudes to learning ….	Computers & Education	Q1	141
2nd	(López, 2010)	The digital learning classroom: Improving ….	Computers & Education	Q1	103
3rd	(Cai et al., 2019)	Tablet-based AR technology: Impacts on students' …	British Journal of Educational Technology	Q1	98
4th	(Barkatsas et al., 2009)	Learning secondary mathematics with technology: Exploring the complex …	Computers & Education	Q1	90
5th	(Roschelle et al., 2010)	Scaffolding group explanation and feedback with …	Educational Technology Research and Development	Q1	90
6th	(Goos et al., 2003)	Perspectives on technology mediated …	The Journal of Mathematical Behavior	Q1	83
7th	(Arroyo et al., 2013)	Gender differences in the use and benefit of …	Journal of Educational Psychology	Q1	69
8th	(Bennison and Goos, 2010)	Learning to teach mathematics with technology: ….	Mathematics Education Research Journal	Q1	60
9th	(Bray and Tangney, 2016)	Enhancing student engagement through the affordances ….	Mathematics Education Research Journal	Q2	59
10th	(Trouche and Drijvers, 2010)	Handheld technology for mathematics ….	ZDM - International Journal on Mathematics Education	Q2	58

Description: SQ= Scopus Quartile in the year of article publication, TC= Total of Citations

The document with the highest number of citations is from Pierce et al, (2007) which discusses various aspects of technology use in mathematics learning, with a diverse focus ranging from student attitudes towards technology to its impact on learning engagement and achievement. The most highly cited article demonstrating the importance of measuring student attitudes towards technology in mathematics was published in the journal "Computers & Education", with 141 citations. This journal dominates the high citation rankings, demonstrating its significant influence in the field of technology education. The large number of citations indicates that these studies make an important contribution to understanding and optimizing the use of technology for mathematics learning.

The majority of the highest-cited documents were published in Q1-ranked journals, confirming that research on technology in mathematics education is of recognized quality and influence in the academic community. Topics covered include the use of devices such as tablets, interactive whiteboards and handheld technology to enhance student understanding and engagement. In addition, research also explores aspects such as gender differences in the benefits of educational technology and professional development needs for teachers. Collectively, these documents contribute to a broader understanding of how technology can be effectively applied to enhance mathematics learning at different levels of education.

After answering all of the first research question (RQ1), the researcher went on to answer the second research question (RQ2) which included an analysis of keyword clustering and keywords novelty that could be recommended for further research in the field on Technological Innovation in the Process of Mathematics learning. This analysis aimed to identify key themes that have been extensively researched as well as finding gaps or areas that still require further exploration. This analysis uses the VOSviewer application with Network Visualization and Overlay Visualization.

Focus Research

In the focus research, the author uses Keyword Occurance ≤ 3 and uses the Network Visualization feature on VOSviewer. So that we get 41 keywords with 6 clusters.

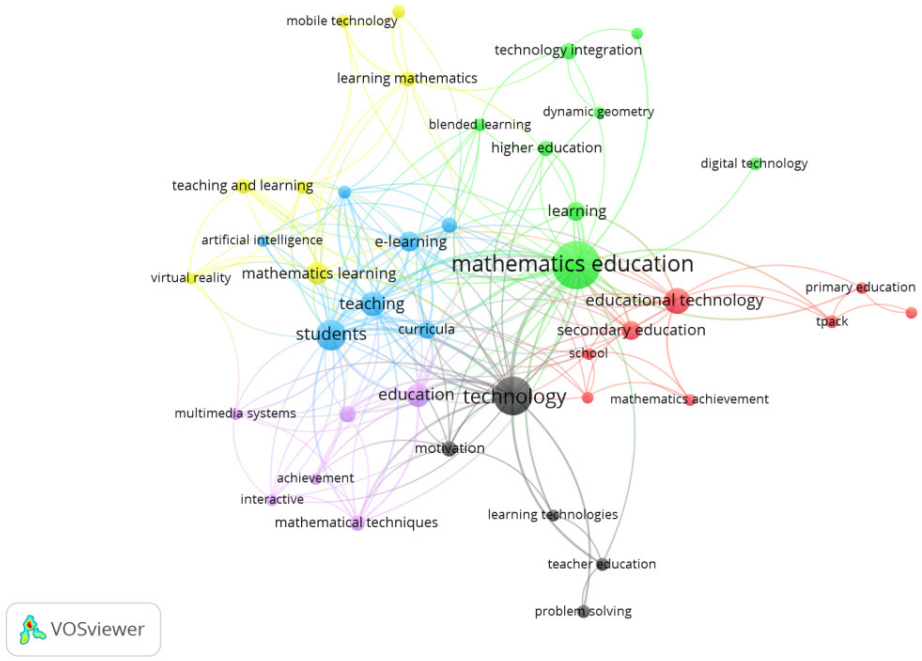

Figure 8. Keyword Grouping on Network Visualization Menu

After clustering with VOSviewer, the author then collects keywords and identifies group names based on the clustering corresponding to the cluster color.

Table 6. *Name Giving Based on Cluster Color Grouping*

Color Name	Keywords	Group Name
Red (8 items/19.51%)	Education Technology, Information Technology, Mathematics Achievement, Mathematics Teachers, Primary Education, School, Secondary Education, TPACK	Learning and Teaching Strategies
Green (8 items/19.51%)	Blended Learning, Digital Technology, Dynamic Geometry, Higher Education, Mathematics Education, Technology Education, Technology Integration	Technology Integration in Education
Blue (7 items/17.07%)	Artificial Intelligence, Curricula, E-learning, Learning Sytems, Mathematics Course, Students, Teaching	Digital Learning Innovations
Yellow (7 items/17.07%)	Augmented Reality, Learning Mathematics, Mathematics Learning, Mobile Technology, Teaching and Learning, Technology Acceptance, Virtual Reality	Immersive and Mobile Learning
Purple (6 items/14.63%)	Achievement, Education, Interactive, Mathematical Technique, Multimedia Systems, Technology Enhanced Learning	Interactive and Multimedia Approaches
Black (5 items/12.19%)	Learning Technologies, Motivation, Problem Solving, Teacher Education, Technology	Pedagogical and Technological Support

Source: VOSviewer

The red cluster titled “Learning and Teaching Strategies” includes keywords that focus on educational technology and how it is applied in the school environment to improve learning outcomes. Elements such as TPACK (Technological Pedagogical Content Knowledge) and the application of information technology are key in designing more meaningful and interactive learning experiences (Tseng et al., 2022). Focusing on primary and secondary education, this cluster underscores the role of teachers in using technology to improve student achievement (Imran et al., 2023). This is particularly relevant to technological innovation in mathematics learning, as teachers need to integrate technological knowledge with effective mathematics

teaching methods (Bakar et al., 2020). This cluster highlights the importance of a holistic understanding between technology education and pedagogy to support more modern and adaptive teaching.

The green cluster entitled "Technology Integration in Education" highlights the application of technologies such as blended learning, digital technology, and dynamic geometry in higher education. These technologies play an important role in creating flexible and interactive learning environments, which support technology-based learning in mathematics. This cluster emphasizes the importance of technological innovations that foster more adaptive and integrated teaching, allowing students to access a variety of digital resources and engage in deeper learning (Haleem et al., 2022). This integration provides new opportunities for developing mathematics curricula that are more relevant to the needs of the times and helps connect theory and real-world applications.

The blue cluster entitled "Digital Learning Innovations" focuses on advanced technologies such as artificial intelligence, e-learning, and customized learning systems. These innovations play a role in creating curricula that can be adapted to the individual needs of students, as well as developing interactive and dynamic learning platforms (Tapalova and Zhiyenbayeva, 2022). In the context of math learning, the application of AI and e-learning systems can help simplify complex concepts and improve student understanding (Akugizibwe and Ahn, 2020). This cluster highlights the huge potential of digital technology to revolutionize the way students learn mathematics, and how technology can support more personalized and effective teaching.

The yellow cluster entitled "Immersive and Mobile Learning" covers technologies such as augmented reality, virtual reality and mobile devices that are changing the way students engage with math learning materials. These technologies create a more immersive and visual learning experience, which is particularly beneficial in teaching abstract concepts in math (Su et al., 2022). Acceptance of the technology by students is also a focus, as the implementation of these advanced tools requires readiness on the part of both students and teachers. Innovations like these allow math learning to be more engaging and interactive, and help students understand the material in a way that is more intuitive and connected to the real world.

The purple cluster entitled "Interactive and Multimedia Approaches" focuses on multimedia systems and interactive techniques designed to enhance technology-based learning. The use of technology-enabled systems for mathematics learning enriches students' experiences with a variety of visual and dynamic representations of mathematical concepts (Flood et al., 2020). This cluster highlights how interactivity and multimedia-enriched learning can make mathematics more engaging and accessible to different types of learners. With technology supporting personalized learning, this approach contributes to innovation in developing students' ability to understand mathematics more thoroughly.

The black cluster entitled "Pedagogical and Technological Support" discusses motivation, learning technology, problem solving and teacher education. This cluster focuses on how technology can be used to support teachers in developing teaching skills and creating learning environments that motivate students to think critically and creatively (Henriksen et al., 2021). In the context on Technological Innovation in the Process of Mathematics learning, this aspect is important to ensure that technology is not only used as a tool, but also as a medium that facilitates effective teaching strategies. By supporting teachers through appropriate training and technological resources, mathematics learning can become more meaningful and encourage students to be actively engaged.

Keywords Novelty

The keyword novelty analysis aims to identify new keywords that have emerged in recent research related to technological innovation in mathematics learning. These new keywords can be recommended for future research to explore relevant and under-discussed topics and encourage the development of innovative ideas in the field.

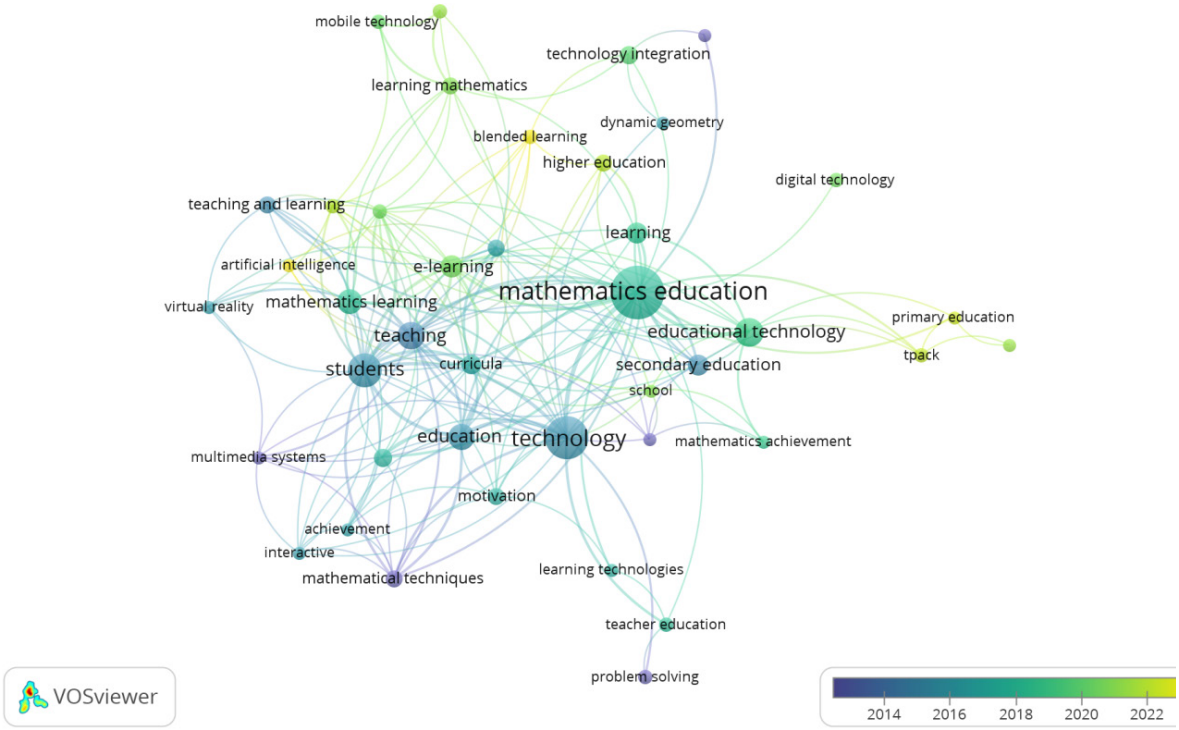

Figure 9. Keyword Novelty Analysis with Overlay Visualization on VOSviewer

The overlay visualization analysis shows that the light-colored keywords indicate that the keywords began to be used in the most recent year and can be used as recommendations for future research related to technological innovation in mathematics learning. The keywords “Artificial Intelligence” and “Blended Learning” are yellow keywords, indicating that these two concepts are newly used in technological innovation in mathematics learning. This suggests a new trend in the incorporation of advanced technology and more flexible learning methods, which may encourage further innovation in this area.

Discussions

The development of education after war has undergone significant transformation, with many countries working to rebuild education systems to support social and economic recovery (Behnamnia et al., 2020). Schools play an important role in the intellectual and social development of children, by providing formal education and shaping character to face future challenges (Tsekhmister, 2022). However, challenges such as limited facilities and resources still exist, which affect students’ learning experiences. Therefore, attention to supportive school and classroom conditions is essential to create an effective learning atmosphere. In this context, technology has an important role in mathematics learning innovation, as it can optimize the learning process, introduce more adaptive methods, and create a more inclusive learning environment, allowing students from different backgrounds to learn more easily and enjoyably.

The development of technological innovations in mathematics learning showed significant growth from 1987 to 2024, with a total of 262 documents published. Since 2010, publications have increased rapidly, especially by 2023, indicating a growing interest driven by technological advances and the need for technology-based learning innovations. The United States and Australia lead in the number of publications and citations, demonstrating their great influence in this field. North America and Asia make

significant contributions to global research, with smaller contributions from other continents such as Africa and Oceania, but with considerable citation impact. Overall, these countries play a key role in advancing technological innovation in mathematics learning, both through their research output and global academic influence. One challenge in global collaboration is the disparity in technological infrastructure between developing and developed countries, where access to necessary hardware and software for technology-based mathematics education is limited in resource-constrained areas. However, this also presents an opportunity to create more cost-effective, accessible technology solutions, with developed countries providing technical support and sharing knowledge to help overcome these challenges.

Universiti Putra Malaysia showed dominance in producing publications focused on this topic, followed by other leading universities in Australia and South Africa. The dominance of universities from Asia and Australia is also evident, reflecting the great influence of these regions in developing and applying technology in mathematics learning. On the other hand, Johannes Kepler University Linz emerged as a very productive institution with many authors who contributed significantly to the development of this topic. Their contributions, both in terms of number of publications and quality of research, illustrate the importance of this institution in research related to mathematics education technology, as well as showing the global trend of increasing interest in technology-based learning innovations.

Journals from different countries, especially those listed in the Q1 category, showed great contribution in advancing knowledge about the application of technology in mathematics education. Although the number of publications varies, some journals with few publications have attracted attention due to their high citation impact, confirming that quality of research takes precedence over quantity. In addition, the highly cited articles, which address aspects such as the use of technological tools and gender differences in the benefits of educational technology, provide valuable insights to improve the effectiveness of mathematics learning. Overall, research in this area continues to grow and make a significant contribution to understanding how technology can be applied to improve mathematics learning at different levels of education.

In the clustering of keywords, various aspects on Technological Innovation in the Process of Mathematics learning were revealed. The application of technology in primary and secondary education is important to improve student achievement, with attention to the integration of technological and pedagogical knowledge. Technologies such as blended learning and dynamic geometry enable flexible and interactive learning environments in higher education. In addition, artificial intelligence and e-learning help create personalized curricula to facilitate student understanding. The use of augmented reality and mobile devices also makes learning more immersive. Multimedia systems and interactive techniques enrich the math learning experience, while support for teachers helps create more effective teaching.

Overlay Visualization analysis shows that the keywords “Artificial Intelligence” and “Blended Learning” are emerging as new trends in technological innovation in mathematics learning. “Artificial Intelligence” has the potential to create a more personalized learning experience, by automatically customizing materials and providing feedback. Meanwhile, “Blended Learning” enables flexible math learning by combining face-to-face and online methods, giving students the freedom to learn at their own pace. Both concepts represent new directions in education and could be the focus of future research to improve the effectiveness of math learning.

Trends in technological innovation in the process of mathematics learning show that Artificial Intelligence and Blended Learning are increasingly becoming the main focus of educational innovation in mathematics. The use of AI, such as on the Matific platform, provides math exercises based on games for K-6 students, utilizing AI to adjust the difficulty level and provide automatic feedback. Microsoft Copilot helps students understand math formulas through step-by-step explanations, improving conceptual understanding and critical thinking skills. Applications like Photomath and Microsoft Math Solver use AI to allow students to solve math problems by providing step-by-step solutions and detailed explanations. Furthermore, future research could propose automatic assessments to measure student engagement and success in AI-based mathematics learning. This includes developing algorithms to evaluate student interaction with the AI system, such as problem-solving speed, error rates, and progress from one learning session to another. The results of this evaluation could be used to provide more tailored learning recommendations based on individual student needs and identify areas that require improvement in the technology-based learning process.

Meanwhile, Blended Learning combines face-to-face and online learning, offering students flexibility in managing their time and learning methods. E-learning platforms enable students to practice math problems

online and see their results immediately, helping them better understand the material. Online discussions on platforms like Google Classroom allow students to share their views on complex topics such as quadratic equations. Video tutorials enable students to learn independently about basic math concepts. The integration of AI and Blended Learning in the mathematics curriculum creates a personalized and flexible learning experience, enhances motivation and student engagement, and bridges gaps in diverse learning needs.

Conclusions

From the analysis, it can be concluded that research on technological innovation in the process of mathematics learning started in 1987 and experienced significant growth until 2024, with a surge in publications occurring since 2010, especially in 2023. Countries such as the United States and Australia lead in the number of publications and citations, demonstrating their great influence in this field, followed by significant contributions from the Asian and North American regions. Universiti Putra Malaysia, along with leading universities in Australia and South Africa, showed dominance in publications related to this topic. Some Q1 journals also play a major role in advancing knowledge about technology in mathematics education, with the quality of research taking precedence over the quantity of publications. Keyword clustering revealed that technological trends such as “Artificial Intelligence” and “Blended Learning” are now emerging as new directions in technological innovation for mathematics learning, offering a more personalized and flexible approach to improve learning effectiveness in the future.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

S: Conceptualization, Writing - Original Draft, Editing and Visualization; HR: Review & Editing, Formal analysis, and Methodology; ZE: Validation and Supervision; ZA: Writing – Review & Editing; RH: Validation and Supervision. All authors have read and agreed to the published version of the manuscript.

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Signmatics: An Interactive Digital Based System for Multimodal Learning of Hearing Students in Bulgarian Sign Language

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Abstract: The proposed scientific text describes an experimental study, the purpose of which is prioritized to test an interactive digitally based system Signmatics for mastering linguistic content in Bulgarian Sign Language (BGSL) by students who study it as a second language (E2). The formed sample includes 62 participants –- students studying in a bachelor's program in the specialty of Special Education. The study uses a quasi-experimental design of non-equivalent groups: an experimental group of 30 students (48.39%) which was subjected to the digitally based intervention and a control group of 32 students (51.61%), trained in conventional ways. The verification of receptive and expressive language skills in BGSL at the level of phonetics, vocabulary and morphosyntax was carried out by applying a standardized language test, decomposed into 3 subtests. The comparative approach to the results of the study convincingly shows that the interactive Signmatics system applied in a real time frame has a high efficiency coefficient in mastering the visual language at the level of vocabulary ($F=26.574$, $p<0.000$), morphosyntax ($F=1.423$, $p<0.001$). At the phonetic level, no statistically significant difference was found between the two groups ($F=0.001$, $p=0.971$), an explanation for which can be sought in the specificity of the visual phonemes, as building blocks of the sign. The latter finding suggests the idea of maintaining continuity between modern digital technologies and traditional strategies for teaching and learning linguistic material which have stood the test of time.

Keywords: *signmatics, digital based system, multimodal learning, Bulgarian Sign Language.*

Introduction

In recent years, the learning of sign language by hearing people as a second language has become an up-to-date issue, generating fruitful discussions and innovative research. In the scientific paradigm of researchers, sign languages, as a significant factor in nurturing social interaction (Adam and Braithwaite, 2022; Kusters, 2020; Balkanska, 2013; Balkanska and Lozanova, 2021), are on an equal footing with spoken languages in terms of their naturalness, vitality, autonomy, complexity and expression (Fenlon et all., 2007; Dimich and Sesum, 2011). Learning a language that is realized in a visual modality different from spoken language (M2) is a real challenge for hearing people, which stimulates the scientific ambition to find ways to optimize sign language learning. Traditional teaching models are being transformed and expanded to include a new "digital" level, in which multimodality as a natural feature of human perception, an important and specific fragment of the categorization of the world, continues to reign – a problem that is the subject of constant scientific interest (Tsankov and Levunlieva, 2024; Tsankov and Dermendzhieva, 2024; Dermendzhieva and Tsankov, 2023; Dermendzhieva and Tsankov, 2022).

In light of these changes, visual language researchers are focusing their creative efforts on using operants and algorithms based on advances in digital technologies for teaching and mastering the individual components that make up their complex composite as semiotic systems.

The Bulgarian Sign Language (BGSL) is a legitimate, strictly regulated language, different from the Bulgarian language, and elevated to a pedestal by the members of the cultural community of Bulgarian

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deaf people. Its teaching and study as E2 (M2) is an integral part of higher education in Bulgaria. The modern language training of specialists in the separate structural units of universities requires special attention in terms of the quality of formation of a wide range of competencies (Lozanova and Stoyanova, 2022; Angelova, 2017), the search, development and application of effective methods and technologies operating in a digital format. This becomes especially relevant at the stage of increasing competitiveness in the global educational space, developing international cooperation of the university in connection with the internationalization and the implementation of academic mobility programs.

On the chronogram of time, signs of introducing digital innovations into the practice of teaching and learning visual language were positioned about two decades ago, when a team of specialists created an interactive system called Sign Tutor (Aran et all., 2009). The interactive technology is designed to master basic language knowledge by hearing students learning Turkish Sign Language (TSL) as a second sign system. The generated visual feedback, providing automatic assessment of the produced sign unit, and the source of information about the precision of the performed sign are among the dominant advantages of the system. The implanted integrated circuit for unifying the parameters of the sign, including non-manual signals – linguistic head movements, give the technology a unique style of functioning.

A major priority in de Villierse (2014) research is the development and testing of a visually-based system for mastering language content in South African Sign Language (SASL). An intriguing feature of the technology, which surpasses existing sign language learning systems to date, is its capacity to produce detailed and specific feedback to the user. The new algorithm, taking into account the user's experience, automatically guides them to the correct model of linguistic behavior. An additionally introduced operation allows the feedback to take the form of a context menu.

The quest to dicovering optimal solutions for early communicative intervention in deaf children (Ackovska, Kostoska and Gjuroski 2012) finds expression in the creation of an interactive e-learning platform in Macedonian Sign Language (MSL). The collection of game modules and panels is oriented towards optimizing language preparation, improving memory parameters and mental capacity in deaf children. They are encouraged to perceive manual symbols reproduced by 3D animations of a child who follows the user's choice: dactylem, word, sign denoting a specific object. A mobile application for children SiLearn, which functions as a visual lexicon, was created by another team of authors (Joy, Kannan and Sreeraj, 2019). Language tests of 28 deaf students show a rapid pace of mastering sign vocabulary.

The research initiative of scientific and cultural figures (Papadimitriou et all., 2025) leads to the successfully implemented SL-ReDu project, which focuses on the teaching and learning of Greek Sign Language (GSL) as E2. The high results achieved by 150 students are determined by the module introduced in the system for visual detection of isolated lexical items, and the HRNet framework for detection of the skeleton of the body, hands and face of the communicator in 2D and 3D format.

Another research project (Vijitkunsawat et all., 2023), demonstrating the value of digital solutions, found evidence of a multimodal learning space modeling technology that stimulated the learning of Thai Sign Language (ThSL). In experimental conditions, students were encouraged to independently select lexical items and practice the language material using animation.

A developed product in the form of an avatar complements the digital achievements related to the study of American Sign Language (ASL) and reflected in the scientific literature (Quandt et all., 2020). The graphic model is three-dimensional and acts as an educator teaching language content at a basic level.

In the systematized scientific analyses on a global and especially on a national scale, a free research niche is still being discovered, which awaits to be updated with new data related to the remarkable potential of software programs offering multimodal options for teaching and mastering a semiotic system functioning in a triad of codes: visual, motor and spatial.

This is a convincing argument that served as a framework for organizing and conducting the experimental study, the goal of which is related to testing an interactive digitally based system for mastering linguistic content in Bulgarian Sign Language by students who study it as a second language (E2). The object of the study is the formation of sign competence in hearing students of the scientific specialty of Special Education, receiving academic training in BGSL, and the subject is the optimization of the educational pedagogical practice for teaching and learning the national visual language through a multimodal educational environment, designed and formed through the resources of the interactive computer program Signmatics.

Signmatics is an interactive multimodal computer program for learning Bulgarian Sign Language (BGSL), including multiple communicative modes – gestural, oral, written, tactile. The digital technology,

version 1.0, was created in 2009 within the framework of the social project Grant M-Tel by the Union of the Deaf in Bulgaria (UBD). A diverse team of highly qualified specialists, distinguished by their creative charge, dedication, responsibility and innovation in their mission to establish and popularize BGSL in a broad social and educational context, participated in the development and administration of the program.

The program consists of several modules. The first module is a lexicon of 5200 sign units, which are a solid basis for the formation of lexical competence in BGSL. Of particular note is the built-in filter, which provides an additional opportunity to separate signs according to grammatical (parts of speech: signs nouns, signs verbs, signs adjectives, signs adverbs, etc.) and age criteria (preschool age, primary school age, etc.).

The second module is related to options for combining signs into complete wholes – sentences, which implies mastering morphological and syntactic skills – an integral part of sign language competence. The submodule with pre-composed grammatical constructions complements the program design by demonstrating the linguistic capacity of Bulgarian sign language.

The third module includes content that introduces the user to the unique essence of BGSL and the distinctive culture of the Bulgarian deaf people. This is extremely valuable information that acts as a motivator for immersion in a new subject.

The last module is intended for checking or self-checking knowledge. The attractive algorithm that is followed turns the mastery of signs into an intriguing activity that leads to successful results.

Materials and Methods

Design

The study used a quasi-experimental design of non-equivalent groups to evaluate the effectiveness of an interactive digitally-based Signmatics system in an educational environment. The choice of design is practically justified – the researcher has the opportunity to form two comparable groups, one of which receives an educational intervention with digital technology, and the other continues to use conventional methods for studying BGSL.

The independent variable was decided to be the digitally based Signmatics system used during the lecture sessions. The dependent variables defined were the following: perception and expression of the sign parameters (phonology), knowledge and use of lexical sign units (vocabulary), knowledge and use of morphosyntactic information (morphosyntax).

The formulated research question concerns the existence of a significant difference between the academic achievements of students who study BGSL using the digital program Signmatics, compared to those who are taught using conventional methods for mastering linguistic content.

The research question suggests the following hypotheses:

H_{01}: The difference between the average levels of operating with the visual-spatial characteristics of signs by students placed in different experimental conditions (using/not using interactive digitally-based technology) will not be distinguished by a high significance value.

H_{02}: The difference between the average levels of knowledge and use of lexical sign units by students in different experimental conditions (using/not using interactive digitally based technology) will not be distinguished by a high significance value.

H_{03}: The difference between the average levels of knowledge and use of morphosyntactic information by students positioned in different experimental conditions (using/not using interactive digitally-based technology) will not be distinguished by a high significance value.

Sampling method and research ethics

Non-random sampling was used for this study. It was formed by 62 statistical units – students from two courses, trained in the bachelor's program "Special Education", a full-time form of training. The students, having an equal start in studying BGSL, were divided into two groups. One group included the students (N=30), who were trained in visual language by applying the digital program (treatment group), while the other group of students (N=32) were mastering sign language competence through a traditional approach (control group).

The preliminary procedure included the preparation of forms certifying the possibility of consent or refusal by the students to participate in the pedagogical experiment.

For the purposes of the study, the researcher conducted a 3-month lecture course on BGSL, with both groups of students being prepared in parallel, but in different pedagogical conditions. The students

from the treatment group were offered training in BGSL through a specialized software interactive language program Signmatics, with the capacity for encoding and decoding signing, oral and written messages; with opportunities for perception and expression at the level of vocabulary and grammar, revision and self-testing of knowledge by using auditory, visual, motor and tactile modalities. The characteristics of the program give a multimodal character to the pedagogical interaction.

Instrument and Procedures

The main instrument used in the study was a standardized test aimed to measure receptive and expressive skills in the Bulgarian Sign Language in 3 categories (phonology, vocabulary, morphosyntax), the elements of which constituted the content of the three subtests. The phonological subtest, through which students could present their skills, included 2 tasks: receptive (33 items) and expressive (28 items). The vocabulary subtest contained items through which students could demonstrate knowledge of the semantic component of the sign (56) and precision in its expression (54 items). Receptive and expressive skills in morphosyntax were also assessed in two tasks. For the first task, 18 items were selected (for expressing plurality, classifying verbs for movement and location, modifications of verbs for type, etc.), and for the second one – 15 items.

The assessment of receptive and expressive skills in BGSL was carried out by the researcher who has 13 years of experience in teaching the basics of Bulgarian Sign Language, and by a specialist – a native speaker of the national sign language. The latter belongs to the so-called CODA group (Children of Deaf Adults).

Data Analysis

The following statistical procedures were used: a Shapiro-Wilk test of normality to check the distribution of the data sets in the four linguistic categories; Cronbach's alpha procedure for examining the internal consistency of items in the three subscales; Descriptive statistics to classify the data and obtain summarized characteristics for the individual variables in the entire sample; An One-Way ANOVA test to assess statistical differences in the results of the 3 domains registered in the two groups. The adopted significance level is α=0.05. The empirical data were processed with the SPSS 16.0 statistical package.

Results

The internal consistency of the scale was calculated using the Cronbach's Alpha procedure (Table 1). The item scores in the three subscales showed very good internal consistency (Cronbach's Alpha=0.846).

Table 1. *Internal consistency between the tests*

Test	Number of items	Cronbach's alpha values
Receptive phonology	33	0.803
Expressive phonology	28	0.813
Receptive vocabulary	56	0.807
Expressive vocabulary	54	0.824
Receptive morphosyntax	18	0.821
Expressive morphosyntax	15	0.851

The Shapiro-Wilk test on all domains assumes a value of p>0.05, which is a clear indicator of normality of the distribution.

Table 2 presents the means and standard deviations for the students' achievements in the three subtests of the two groups, and Table 3 draws attention to the significance effect of the digital program Signmatics in relation to different Sign language contexts.

Table 2. *Means and Standard Deviations for the student's achievements in the three subtests*

Subtests	Group	N	*Mean*	Standard Deviation
Phonology	Control	32	14.62	5.28
	Treatment	30	14.64	5.29
Vocabulary	Control	32	15.43	4.57
	Treatment	30	17.70	5.42
Morphosyntax	Control	32	15.41	4.75
	Treatment	30	16.84	5.40

Table 3. *Differences between students in different Sign language contexts*

Sign Language contexts	Group	M	SD	F	Sig.
Phonological	Control	14.62	5.28	0.001	0.971
	Treatment	14.64	5.29		
Lexical	Control	15.43	4.57	26.574	0.000
	Treatment	17.70	5.42		
Morphosyntactic	Control	15.41	4.75	1.423	0.001
	Treatment	16.84	5.40		

H_{01}: The first hypothesis raised was that the difference between the average levels of operation with the sign parameters by the students positioned in different experimental conditions would not be distinguished by a high significance value. The registered results did not reveal a statistically significant difference in the performance of the two groups, which means that the application of the interactive digital program Signmatics did not have a significant main effect on the phonological component (F=0.001, p= 0.971). In comparative terms, the treatment group achieved results (M=14.64, SD=5.29), which were similar to those of the control group (M=14.62, SD=5.28). This was an argument for accepting the first null hypothesis.

H_{02}: The second hypothesis contained a statement about the absence of a statistically significant difference between the average levels of recognition and reproduction of lexical sign units by students in different conditions of pedagogical interaction. In contrast to the previous linguistic category, statistical procedures identified a significant effect of digital technology on academic achievement in the lexical subtest (F=26.574, p<0.000). The comparative analysis of the arithmetic mean values in the two groups showed a convincing superiority of the treatment group (M=17.70, SD=5.42) over the control group (M= 15.43, SD=4.57) in relation to the studied domain. A prerequisite arose for rejecting the second hypothesis.

H_{03}: According to this hypothesis, the difference between the average levels of knowledge and use of morphosyntactic information by students trained in different pedagogical conditions would not be distinguished by a high significance value. By analogy with the lexical domain, the interactive program also demonstrated a significant effect at the morphosyntactic level (F=1.423, p<0.001). The observed difference between the average values in the groups showed a statistically significant performance of students from the treatment group (M=16.84, SD=5.40) compared to the control group (M=15.41, SD= 4.75), which is why this hypothesis was also rejected.

Discussions

The conducted experimental study was motivated by the need to supplement and enrich the scientific and applied research niche in a field that offers digital solutions for multimodal learning in a language that is unique in itself with its multimodal nature. The research focus was directed at identifying the effect of the application of an interactive digitally based system Signmatics in teaching Bulgarian Sign Language (BGSL) to students who study it as a second language (L2). The testing of language skills in their receptive and expressive aspects was carried out in three domains: phonology, vocabulary and morphosyntax. Depending on the pedagogical conditions of the language training in BGSL, the respondents were differentiated into two groups: a treatment group, in which the mastery of linguistic

content was ensured by the Signmatics software program, and a control group, in which the students studied the basics of BGSL using generally accepted methods. Three hypotheses were raised in support of the formulated research question.

The first hypothesis assumed the absence of a statistically significant difference in the phonological skills of students situated in different experimental conditions. The students from the treatment group demonstrated higher achievements compared to the students forming the control group in the subtests for perception and expression of the spatial-kinetic characteristics of the sign but the difference was reported as statistically insignificant. The registered result was not surprising given the complex structure of the sign, the parameters of which are distinguished by simultaneous realization in the signing space. The performance of the first language task allowed the most accessible and at the same time the most challenging parameters of the visual lexical sign for the students‘ perception to come to the fore. The results formed a differentiated picture, outlining a general trend of precision in the perception of the participants from both groups in the order of more than 70% on average for each parameter. The highest degree of accuracy was registered in the area of localization and orientation of the palm. The errors made were the least frequent ones: about 40% for both groups regarding palm orientation and below 40% for the localization parameter. These reactions clearly show that localization, followed immediately by palm orientation, are the first visual-spatial segments that are learned by hearing adults (Schmidt, 1993). In the remaining three parameters, and especially in linguistic movement and non-manual markers, the quantitative indicator of accuracy in perception dropped to 53%. Non-manual markers turned out to be a weak link in the students‘ linguistic behavior, which was logical, taking into account earlier studies of the mentioned characteristic (Beal, 2020). An interesting trend was found within the limits of the errors generated. When the sign presented for perception was produced close to the face (as a location), the students showed a tendency to perceive differences in non-manual signals. In contrast, the distant position during the execution of the sign led to the omission of changes, which had a persistent effect among the participants. The most logical explanation for this linguistic situation can be found in the visual attention that students fix primarily on determining the shape of the hands and the movement, while at the same time the face of the communicative partner remains largely outside the field of their observation. In the second task, which was related to the assessment of the expressive aspect, the movement and configuration of the hand also turned out to be problematic areas of implementation. The highest error distribution indicator is in the movement parameter (28%), closely followed by the shape of the hand (25%), non-manual markers (23%) and the orientation of the palm (20%). The lowest error rate is registered in the in the parameter localization (14%). The errors found are very similar to those registered in the first task, with a small change in the non-manual markers, which in terms of accuracy of execution overtake the configuration of the hand.

The analysis of the data showed that the phonological component was the only one in which students receiving the Signmatics educational intervention did not achieve statistical improvement compared to their colleagues from the control group. There is a deep reason for the similar results obtained in the two phonological tasks. Most likely, the interference of spoken language manifests its effect, especially when it comes to non-manual signals. Expressive facial features accompany verbal languages in the course of communication, but do not convey linguistic data in the way that these elements perform a linguistic function in visual languages. Therefore, students mastering visual language as a second sign system make enormous efforts to decompose the broad category of “facial expression” into specific segments of linguistic information.

The findings in this domain are a reference to a conclusion related to the use of the interactive computer technology together with traditional forms of sign language instruction. Placing special emphasis by the teacher on the specific features of the five parameters of the visual-spatial sign, explanations of the way in which the sign is motivated, as well as the development of tests to verify phonological knowledge, are among the effective strategies for forming phonological competence in students mastering BGSL as E2.

The second hypothesis assumed that the difference in the perception and production of sign lexical items by students placed in different experimental situations would not have statistical significance. Vocabulary is a fundamental aspect in the acquisition of sign language. Mastering a foreign language, which is realized in a new modality for native speakers of the spoken language (M2E2), requires a major lexical volume. In this domain, a significant contrast was registered in the academic performance of students from the two groups, in favor of the treatment one, which created a condition for rejecting the null hypothesis.

Within the first task, designed to identify receptive skills, out of the 56 lexical units set, representing

different “parts of speech”: signs nouns, signs verbs, signs modifiers, a high percentage of correctly recognized signs (95.5%) was noted among students drawing lexical knowledge from the interactive program, and 80.7% among those whose lectures were held in an environment not equipped with digital means. Both results are visibly high, but the statistically significant preponderance belongs to the treatment group. To some extent, the high values can be explained by the lack of minimal pairs of sign units in the constructed lexical task, which strategy was used to assess the phonological component. The general tendency for maximally accurate perception can be due to the different human models of representation of gesture signs that are included in the interactive program. During the training, the students had the opportunity to observe and imitate all the specialists who have a different manner of presenting lexical signs, which increased their interest in enriching their lexical cdmpetence.

A statistically significant advantage in the lexical capacity of the students participating in experimental training in BGSL was registered when performing the second task, the content of which was aimed at establishing their expressive skills. In addition to the quantitative aspect (87.3% ^ 73.7%), the reproduction of signs was distinguished by accuracy, which was more typical for the representatives of the treatment group. The strong expression of this qualitative characteristic is due to the uniform amplitude and the constant pace of “articulation” of signs by the performers of sign production recorded on the digital device. In the traditional setting, the teacher, in his or her effort to convey knowledge about the reproduction of the signs and subject to the specifics of “live” performance, can change the amplitude and pace of expression, and this probably led to exaggerated articulation in students, on the one hand, or to a lack of accuracy in performance, on the other.

The results of the specific empirical study are indicative of the role of digital technology in building lexical erudition, as well as the degree of mastery of a lexical database. Its advantages are reflected in the students‘ performance in both language tests and strengthen the effect on their assessment of correct production. The ability to choose a communicative option allows them to fully immerse themselves in the language situation, and the presence of feedback is their corrective for the language actions they have taken.

The third hypothesis postulated the absence of a statistically significant difference between the academic achievements in morphosyntax of the students from the two groups. The mastery of the morphosyntactic rules of the BGSL was assessed in two tasks. The performance of the participants in the treatment group was clearly influenced by operating with the software program, as evidenced by the higher results recorded in the first language task for the perception of morphosyntactic structures (71.57% ^ 58.69%). The interactive software motivates students to perceive linguistic material that functions through rules completely different from oral language. The multimodal component of the program provides students with an alternative format for mastering morphosyntactic concepts. In the second task for measuring expressive skills, the students from the treatment group again had greater success in arranging lexical units in sign syntactic chains. The quantitative expression of correctly reproduced morphosyntactic constructions is about 72.69%. The accuracy rate decreased sharply in their colleagues (59.79%). Omission of signs was observed almost three times more often in the control group. There were also cases in which participants stopped after reading the sentence and showed all nonverbal signals of confusion before proceeding to produce the wrong variant.

It should be noted that this result was lower than the result in the lexical probe, which means that the performance of one perceptual task does not predict the specificity in the implementation of another. At the same time, achievements in the impressive component within one linguistic category can serve as a basis for predicting the status of the expressive component.

Conclusions

The conducted experimental study was focused on identifying the effect of the use of digital technology on the mastery of linguistic content in BGSL by students studying it as a second language. Attention was concentrated on assessing their academic achievements in three linguistic categories: phonology, vocabulary knowledge, morphosyntax by administering a language test decomposed into three subtests for diagnostic verification of receptive and expressive skills.

The results of the implementation at the vocabulary level showed a remarkable change in the group of students placed in a digital educational environment. They dominated in terms of accuracy, demonstrating their capabilities in both modal modes – receptive and expressive.

The findings revealed that the digital application positively affects the speed of learning and consolidation of morphosyntactic concepts. The statistically significant improvement belonged again to the students from the treatment group. Although the result in this domain was lower than the lexical achievements, it is a clear indicator that the interactive program Signmatics can be a promising, evidence-based, additional strategy in the student audience where the basics of BGSL are studied.

The mastery of the phonological component was similarly represented in both groups of students, which is a reference to other factors determining success in this area. One of them is the new modality within which sign language is implemented. The different linguistic situation requires the acquisition of a new motor skill and its application for the creation of an entirely new phonological component with a set of other articulatory organs that do not overlap with those involved in the phonological structures of the spoken language. This inspires the idea of achieving synchronization between digital and traditional educational technologies, which find an intersection in multimodality.

Despite its solid traditional foundation, BGSL teaching has been modified over time through the integration of modern and creative elements, such as digital technologies. This combination of conventionality and creativity can lead to significant success in mastering a unique linguistic code that has a clearly defined role.

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Conflict of interests

The author declares no conflict of interest.

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Digital Game-Based Learning's (DGBL) Effect on Students' Academic Performance

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Abstract: Digital game-based learning (DGBL) has redefined education in recent years. Instead of replacing conventional methods of instruction, the aim is to make learning more complex and adapted to how students really engage with the modern world. This study aims to collect data that will assist educators, students, legislators, and creators of digital games in recognizing the value of the DGBL approach to education. Together, they may enhance and modify these approaches to better suit students' requirements and enhance their academic performance. The study's conclusions may significantly affect future applications of digital educational games in educational settings. Since they could offer a deeper comprehension that would enable students' benefit from personalized instruction through artificial intelligence (AI), while at the same time using immersive technologies would increase students' involvement, interest, and motivation for learning in a virtual environment. A questionnaire was emailed to 328 students at all three study levels, as well as faculty and administrative personnel from Megatrend University in Belgrade, who took part in the study. According to the findings, participants believe that a) if digital games and educational content are combined in learning, students are more likely to increase their learning efficiency in this way; b) if a digital game-based learning (DGBL) approach provides a dynamic and engaging learning environment, it is more likely to increase student motivation and participation in the learning process; c) if digital game-based learning (DGBL) includes rewards, feedback, and competition, there is greater potential to significantly improve student learning outcomes; d) if digital game-based learning (DGBL) is supported by artificial intelligence (AI), which enables personalization, the learning is more likely to dynamically adapt to each student's performance.

Keywords: *Digital Game-Based Learning (DGBL), digital games, students, Artificial Intelligence (AI), personalized learning, immersive technologies.*

Introduction

The most common computer activity at home for children and adolescents is playing computer games (Harris, 2002). Digital games have a significant impact on young people's lives by generating a strong sense of excitement and connection (Kirriemuir and McFarlane, 2004). A vast selection of games and instructional apps are continuously being updated on the mobile market. As a result, youth encounter a multitude of educational programs that provide various approaches to comprehension, instruction, and the integration of information, science, math, and artistic creativity (Liao et al., 2019). Statistics on the global game-based learning industry income show that this market has expanded from 3.5 billion USD in 2018 to 24 billion USD in 2024 (Clement, 2021). This market is anticipated to develop at an exponential rate during the next years. At a compound annual growth rate (CAGR) of more than 27%, it will reach nearly $55 billion in 2029 (Thebusinessresearchcompany, 2025).

Students' social conduct and academic performance have been found to be impacted by digital gaming (Rahayu, 2021). According to the National School Boards Association (NSBA), students who join esports programs have better attendance (+10%) and grades than their peers who do not participate in esports (Intenta.digital, 2021). From a theoretical standpoint, there are a number of benefits to using games for education. First of all, games can offer problem-based, active, and multisensory learning. Gamers may engage with wider communities in game worlds and receive responses instantly. Last but not least,

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games can offer score-based self-evaluation (Chen et al., 2018). Research indicates that using games in the classroom has a good impact on learning and can effectively raise achievement (Chen et al., 2018). Playing games improves visual-spatial abilities, which are helpful in engineering and science (Din and Calao, 2001). Educational digital games are more than just teaching tools. Modern games offer students a dynamic learning platform by simulating real-world scenarios, problems, and settings (Sheehy et al., 2014). By engaging in learning-by-doing activities, students may combine their new knowledge with their prior knowledge and experiences. This integrity helps them learn more effectively (Pitarch, 2018).

Digital educational games are computer programs that mimic real-world situations to provide an engaging learning environment (Kapp, 2014). The "stimulus-response" theory, another name for behaviorist theory, is used in digital educational games. These games gradually provide clues from simple to complicated, offering students a variety of learning opportunities at varying levels of difficulty. Scores that serve as feedback encourage students to meet the instructor's expected response by acting as a stimulant (Fokides, 2018). Digital games are advantageous due to their multimodal nature, variety in terms of the authentic environments and experiences they can replicate, autonomy, feedback and reward systems, scaling of difficulty and progression, chances for experimentation, and alignment with constructivist learning theories (Yu et al., 2021). Digital games and educational content are combined in digital game-based learning (DGBL) to pique students' attention and give them the chance to improve the efficacy of their learning. Students consequently have a favorable lifelong perspective on education and information (Cheng et al., 2013). Digital games can assist in molding students' emotions and behaviors by positively impacting their perceptions of control and benefit, as well as their affective and behavioral components. Actually, the goal is to entertain the students and encourage both behavioral and emotional engagement in the activities (Sarıgöz et al., 2018). Furthermore, games may improve students' capacity for problem-solving and analysis as well as their social abilities (Kirikkaya et al., 2010).

Although different scholars may have different definitions of DGBL, most of them concur that it offers a motivating learning environment to improve student performance by utilizing the benefits of digital games (Byun and Joung, 2018). Numerous studies have demonstrated the beneficial effects of DGBL on a wide range of student learning outcomes, including information acquisition, cognitive and perceptual abilities, affective and motivational outcomes, and behavior modification outcomes (Hussein et al., 2022). According to a study by Li et al., students who played educational digital games showed greater motivation to learn. Therefore, these games can be viewed as "stimuli" that have the potential to enhance students' motivation for learning (Li et al., 2024). A major move toward more effective, individualized, and interesting learning experiences is represented by the incorporation of 3D games, virtual worlds, and cutting-edge AI into the classroom. Teachers can construct immersive learning environments that catch students' attention and promote a deeper comprehension of difficult subjects by strategically organizing instructional content around potent gaming dynamics and utilizing the most recent technological breakthroughs (Axon Park, 2024). With technology playing a key part in changing students' learning, the future of DGBL is becoming increasingly fascinating. AI-driven personalization is one of the most exciting developments. In this approach, learning is dynamically tailored to each student's performance and learning preferences, making learning more interesting and enhancing retention as it goes (Paradisosolutions, 2025).

The consistent and repetitive use of the Internet to play games with other players on a regular basis is known as digital game addiction, and it can have detrimental effects on many facets of life. Since gaming is now easily accessible on a wide range of devices thanks to recent technology advancements, digital game addiction has grown in frequency and severity as a major public health concern (Mohammad et al., 2023). Mental tension, poor academic performance, insomnia, suicidal thoughts, a decline in sociability and self-efficacy, and a drop in life satisfaction are all consequences of gaming. The negative effects of excessive gaming extend to a person's emotional, mental, and physical health (Mardian and Hastono, 2019). Due to students' neglect of healthy food and sleeping patterns, digital gaming addiction has had a negative impact on their health. When students spend too much time playing online games, they become distracted and may engage in harmful behaviors like gambling, stealing, threatening others, or even considering suicide (Hanafie and Makassar, 2022). The usage of digital education-based games in communities and schools has grown in popularity in recent years; however, this has also caused families to worry about the creation of uncertainties over the detrimental effects of these games on youth (Konok et al., 2021). Notwithstanding all of the benefits, some experts think that educational games may worsen motor skills, develop addiction, and raise hostility. To better understand how and what factors influence children's use of digital

games, the majority of researchers have called for additional research (Lazarinis et al., 2020).

Literature review

The range of genres and topic areas in which game-based learning is used can make its definition difficult to define. Nevertheless, game-based learning (GBL) can be thought of as a way to improve students' learning experiences by integrating games with course objectives (Roodt and Ryklief, 2019). Using digital games as teaching tools to accomplish learning objectives is known as digital game-based learning (DGBL) (Prensky, 2001). By introducing competitive processes, accomplishment systems, and reward mechanisms, digital game-based learning (DGBL) offers students demanding, dynamic, and engaging learning environments that greatly increase students' motivation and participation in the learning process (Chen et al., 2018).

According to research, DGBL can be more successful than traditional approaches in a number of subject areas, such as math instruction, foreign language learning, science study, and healthcare (Gentry et al., 2019). Virtual characters, challenges, quests, awards, avatars, and other well-designed game features are what make DGBL so appealing, engaging, and inspiring (Abdul Jabbar and Felicia, 2015). According to research in the literature, students' motivation, engagement, attitude, and focus can all be improved by effective game design and planning for digital game-based learning (Cai et al., 2022). Because digital games offer more depth in terms of gameplay and storyline, it is crucial to remember that they are more sophisticated than simple drill/practice games (Ertmer et al., 2012). Simulations that aim to capture the intricacy of real-life circumstances can be found in this kind of game. As an alternative, they can present fictitious or even fantastical situations to encourage involvement and immersion with gripping stories. They have been created to reflect real-life circumstances and to fulfill instructional objectives and key end purposes (Kapp, 2014).

Research indicates that when game-based learning was used, students spent 93% of class time on task, compared to 72% when it wasn't (Nisbet, 2024). As an indicator of engagement, 81% of students reported having fun while performing game-based activities during the summer semester, according to a study done a few years ago by de Carvalho et al. (de Carvalho et al., 2016). By providing students with instant feedback, games are supposed to help young people enjoy learning, increase their self-esteem, creativity, and imagination, and guide them to the right knowledge (Gurpinar, 2017). Educational games are a learner-centered approach that motivates students, makes instruction more efficient and pleasurable, and allows them to have fun (Boghian et al., 2019). Predetermined rules and objectives, quick feedback on students' activities, and a gradually increasing degree of difficulty are all important components of DGBL environments (Mayer and Johnson, 2010). The results of numerous researches show that adding rewards, feedback, and competition to DGBL can greatly enhance learning (Yang et al., 2022). Learners' critical thinking skills are enhanced via game-based learning, as well. When playing a game with others, students must cooperate and exchange ideas. Because of this, students must listen to and consider the opinions of other students before choosing their next move (Mao et al., 2022). Processes that let students take control of their own education are included in DGBL. When learners receive immediate feedback in the game regarding their knowledge gaps, they are immediately assigned game activities to help fill up these areas that are thought to need more practice (Harding, 2023). In these games, students must complete challenging activities in a set amount of time to receive points. More points are awarded for quicker completion times, and points can be redeemed for exclusive incentives, encouraging students to take charge of their education. Additionally, the digital gaming system shows the names of students who perform well, fostering a sense of accomplishment that encourages good behavior like paying attention in class (Fokides, 2018). According to O'Donovan et al., DGBL leaderboards would encourage competition and a sense of community among like-minded groups (O'Donovan et al., 2013). When their points are displayed on the scoreboard, learners feel motivated to improve (Alhebshi and Halabi, 2020). Students will continue to replay the game in order to enhance their performance, which will improve their learning performance (Behnamnia et al., 2020). Additionally, when students see that their peers have won specific game aspects or have attained a high ranking on the leaderboard, they could try harder to do better in games (Huang and Hew, 2018).

The following are just a few of the many examples of game-based educational platforms that aim to boost student engagement and productivity by integrating gaming components into the training approach. Incorporating game-based learning into educational environments was pioneered by platforms "Blooket"

and "Gimkit." To increase player involvement, they provide a range of game modes. Educators can use Blooket's variety of gaming possibilities to make learning engaging and dynamic. However, Gimkit has a special feature called an in-game economy that allows students to earn points and spend them to buy improvements, creating a fun and competitive learning environment (Miller, 2024). A game-based learning platform called "SC Training" incorporates various engagement components to help students improve their course completion rates while guaranteeing a productive learning environment. This application has an integrated writing tool with interactive templates such as true or false, letter jumble, image/word match, and many more (Bariuad, 2022). Students who successfully complete drill-and-kill grammar and vocabulary activities on the app "Duolingo" earn experience points that may be used to advance to more challenging exercises, gamifying language learning. Students can make their own avatars and inhabit a 3D environment in "Second Life," a virtual reality that can facilitate text communication and lessen speech anxiety (Uwaterloo, 2024). A version of Minecraft called "Minecraft Education" was created specifically for classroom instruction. This edition is educational for students of all ages. Teachers can use the materials they have in-game to make their own lesson plans. Furthermore, a number of lesson plans covering a wide range of topics, including language arts, physics, history and culture, computer science, art and design, and math, are now available (Minecraft, 2025). In order to engage and inspire students to learn science, "Alien Rescue" combines gaming aspects, play, and authenticity to create a lighthearted experience with a purposefully problem-based narrative. Students are asked to participate in an urgent United Nations rescue expedition to save the distraught aliens in the open-ended game scenario, which puts them in the role of young scientists. Through a 3D immersive, sensory-rich method, a playful fantasy experience is combined with this genuine scientific investigation process (Lee and Liu, 2017). Designing gamified content for microlearning is made possible by "Centrical," a powerful gamification training tool. To assist players in adopting the proper behaviors, practicing skills in a risk-free virtual environment, and improving the general knowledge and abilities they require, the platform lets users create narrative mission-based games, set up prize tournaments, or tailor learning challenges (Bariuad, 2022).

A 2023 study that involved 69 students learning English as a second language tested vocabulary acquisition abilities using "Quizziz," a DGBL tool. Students were divided into two groups for this study: the experimental group practiced vocabulary using Quizziz, while the control group practiced vocabulary in their mother tongue. The experimental group did noticeably better than the control group, according to the data, proving the value of DGBL (Nisbet, 2024). Anderson et al. conducted a study to examine the effect of failure in learning by examining the gaming habits and discussions of 88 middle school students who were playing the educational video game "Virulent." They discovered that players learned more effectively when they worked together, with more accomplished players sharing their techniques with less successful peers (Anderson et al., 2018). According to Khan et al., students are more engaged when instructional design is oriented toward DGBL (Khan et al., 2017). A study by Yurdaarmagan et al. demonstrated that, in contrast to the conventional method, students' academic success is increased when using a DGBL approach. Students (a total of 152) were split up into two groups for their research. While the first group received a standard teacher's lecture, the second group engaged in game-based learning in a laboratory setting. The results of the study demonstrated that the two groups' test scores differed significantly, with the group that engaged in game-based learning in a lab obtaining, on average, 10% higher scores (Yurdaarmagan et al., 2015). Chen et al. investigated the efficacy of digital game-based vocabulary learning in a meta-analysis study. To examine the data from a few chosen studies, they employed Comprehensive Meta-Analysis Version 3. The data gave them an approximation of how well language learning was impacted by DGBL, and it revealed that study participants' vocabulary acquisition had increased (Chen et al., 2018). US students who participated in DGBL and the effect this approach had on their academic performance were examined in a study by Liu et al. The digital game "Alien Rescue," was utilized with the 220 students who took part in the study for three weeks during their regular science class. Throughout the study, a science knowledge test was used to evaluate the learning performance of the students. Participants in the study took the test both before and after playing the digital game. The test results revealed a notable rise in the percentage of right answers (over 80%) in comparison to the results obtained prior to the use of the digital game (around 50%). In this specific study, the results showed that participants who used DGBL significantly increased their scientific knowledge (Liu et al., 2011).

However, there are drawbacks to DGBL as well. These are mainly reflected in the fact that these games require time to learn and play correctly, occasionally require additional, costly materials, and some-

times call for pedagogical and technical support, which naturally calls for more resources (Discoverdigital, 2020). DGBL can be very entertaining and motivating, but it can also be distracting. A clear expectation for learning time must be established with students because some may find the desire to continue playing the game too strong (Harding, 2023). Time, money, and technological resources might not be easily accessible in some educational settings. Furthermore, game distractions can occasionally occur if they are not properly monitored and controlled. Lastly, game-based learning is not a good way to teach every subject or skill. Using games to communicate abstract or difficult concepts could be tough (Callahan, 2024). Another problem that arises with DGBL, but also with playing all digital games in general, is the threat to players' cybersecurity. The following are some of the most frequent cybersecurity threats that students encounter when playing digital games: a) Phishing attacks, in which hackers obtain user credentials. By doing this, an attacker can obtain valuable in-game elements that they can either keep for themselves or sell on the black market; b) A data breach as an attack on the gaming corporation whose systems may include a variety of sensitive data. Personally identifiable information (PII), such as the player's name, address, and credit card information, is often owned by a gaming company. The sites might be targeted by cybercriminals who want to steal data to resell on the dark web or utilize in future assaults; c) To obtain access to user accounts, another popular cyberattack is credential stuffing. The attacker in this instance is making use of weak passwords, which is a frequent issue (Behnke, 2023).

When it comes to learning, artificial intelligence-enabled game-based learning establishes a new paradigm in which the younger generation uses digital technology, including mobile or ubiquitous gadgets (Chen et al., 2022). The role of AI in digital games in education was conceptualized by McLaren and Nguyen in two ways: as games that use AI to function and interact with players and as games that have been created and/or expanded using AI techniques (McLaren and Nguyen, 2023). Scholars have been attracted to the argument that AI applications can enhance adaptability in game-based learning. Personalization, game difficulty balancing, assessment, player analytics, competence modeling, social gamification, language technologies, and emotional computing are just a few of the AI-based features covered by the game design elements that enable learning (Westera et al., 2020). Motivation and engagement, two essential components of effective gamification, can be greatly increased by this personalized approach (Parody et al., 2022). Researchers have discovered that AI-powered chatbots can improve learners' emotional, behavioral, and metacognitive awareness in virtual reality gaming learning environments (Liang et al., 2024). Also, DGBLs are important data sources for AI training, which aims to improve individualized experiences and get a deeper knowledge of learners. The majority of current efforts focus on using digital games to train AI algorithms by taking advantage of the organized progression that is a feature of game design (Silver et al., 2017). In AI-driven DGBL, feedback can be considered an affordance that extends beyond conventional evaluations. Both educators and students can get current and pertinent information through this dynamic and ongoing process. By highlighting not only the informative aspect of identifying potential student misunderstandings but, more importantly, by generating feedback that is practical and encourages a cycle of continuous development, this particular affordance may enhance the quality of feedback given (Romero et al., 2024). To guarantee that AI-driven adaptations continuously serve educational purposes, it is imperative to make sure that game mechanics are in line with learning objectives. This alignment becomes more complicated with AI and calls for careful design (Kingsley and Grabner-Hagen, 2015). The use of AI in education does, however, present some serious difficulties. Careful thought must be given to data privacy and AI bias concerns (Wang et al., 2024). Despite the undeniable benefits that DGLB's application of AI provides to the field of education, extra care must be taken in the near future to safeguard students' cybersecurity. In any event, more precise legislation must be passed at the state level, and those who engage in such illicit cyber activity must be suitably identified and prosecuted (Baltezarević and Baltezarević, 2021). However, the dilemma comes from the potential that resolving security issues could jeopardize privacy protection (Baltezarević and Baltezarević, 2015).

Game-based learning's remarkable effect on students is largely due to its seamless integration with cutting-edge technology like augmented reality (AR) and virtual reality (VR). This tasteful combination improves the educational process overall and opens up new avenues for student participation and interaction (Sharma, 2023). The virtual reality (VR) and generative artificial intelligence (AI) technologies were used to build the immersive game-based learning platform known as "LearningverseVR." Using a shared computer and webcam, this platform offers an immersive learning environment where students may take on the role of avatars to interact with virtual items and other avatars. They can also utilize unique collabo-

ration tools to build activities (Song et al., 2024). Research is still being conducted, but a number of case studies have shown how effective these tools are in classrooms. In science classes, for instance, virtual labs let students perform experiments in a secure environment, and historical reconstruction games let players immerse themselves in past cultures. In addition to enhancing students' comprehension, these experiences pique their interest and cultivate a passion for learning (Axon Park, 2024).

Objective of the research

This study examines how students' academic performance is impacted by digital game-based learning (DGBL).

One main and three supporting hypotheses were developed in order to fulfill the research's objective:

H_0: If digital games and educational content are combined in learning, students are more likely to increase their learning efficiency in this way.
H_1: If a digital game-based learning (DGBL) approach provides a dynamic and engaging learning environment, it is more likely to increase student motivation and participation in the learning process.
H_2: If digital game-based learning (DGBL) includes rewards, feedback, and competition, there is greater potential to significantly improve student learning outcomes.
H_3: If digital game-based learning (DGBL) is supported by artificial intelligence (AI), which enables personalization, the learning is more likely to dynamically adapt to each student's performance.

Materials and Methods

Pattern and procedure

With a disclaimer that the study is being carried out solely for scientific purposes, the questionnaire used to assess participant attitudes was sent to 350 email addresses belonging to students at all three study levels, as well as to professors and administrative staff of a Megatrend University in the Republic of Serbia. A total of 328 accurately and completely filled questionnaires comprise the sample that served as the basis for the research, namely: 186 (56.7%) male and 142 (43.3%) female (M=1.43, SD=.496), of which 8 (2.4%) with elementary school, 98 (29.9%) with secondary school, 136 (41.5%) completed high school/college, 67 (20.4%) completed master's degree, and 19 (5.8%) completed doctorate (M=2.97, SD=0.913). The age-related structure of the respondents demonstrates that 114 (34.8%) were aged 26-35, 76 (23.2%) were aged 18-25, 68 (20.7%) were aged 46-55, 55 (16.8%) were aged 36-45, and 15 (4.6%) were aged 56-65 (M=2.49, SD=1.186) participated in the research.

In order to ascertain the respondents' socio-demographic characteristics, the questionnaire was designed with three questions: gender, age, and professional qualifications. After that, 15 statements were created to investigate the responses from participants regarding the application of digital game-based learning (DGBL) in educational settings. A software program for data processing and analysis (IBM SPSS Statistics) was used to process the data. The analysis of the gathered data was done using descriptive statistics (average value, or M, and standard deviation, or SD) and statistical inference. To assess the obtained values of Spearman's rank correlation coefficient rho and Pearson's correlation r, we used a value scale that states that a correlation is weak when $r \geq 0.1$, moderately strong when $r \geq 0.3$, and strong when $r \geq 0.5$ (Field, 2009, p. 100).

Instruments

For further research on the specific research assignment described in this paper, eight variables out of a total of fifteen were selected, and a subscale was created from them. The reliability of the scale was measured by Cronbach's alpha coefficient, which showed that $\alpha = .913$. The mean values of the subscale range from 2.72 to 3.44., which shows a high value of the internal consistency of the scale (Briggs and Cheek, 1986, p.115).

The analysis employed correlation analysis, scale reliability analysis, and descriptive statistics.

A Likert-type scale with five points was used to analyze the format of the responses to the statements (from 1 = I do not agree at all to 5 = I completely agree).

Results

Using correlation analysis, we examined the responses on the following statements to verify the validity of H_0: (T1) Digital gaming should be part of the learning content (M=3.32, SD=1.091) and (T2) digital games in education contribute to the effectiveness of learning (M=3.44, SD=1.335).

Table 1. *Presentation of correlation data and the coefficient of determination for H_0*

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Gamma	.602	.046	11.194	.000
	Spearman Correlation	.563	.046	12.289	.000[c]
Interval by Interval	Pearson's R	.571	.046	12.566	.000[c]
N of Valid Cases		328			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

According to Table 1's results analysis, the Chi square test of independence demonstrates the statistical significance of the impact on the result $\chi 2(16,1)$ 483.414[a] =, $p < 0.01$. Significance ($p \leq .05$) indicates how certain one can be that the relationship. $p < 0.01$ shows that the intersection of variables is statistically significant. Spearman's rank correlation coefficient rho = 0.563 and Pearson's linear correlation r = 0.571 indicate how strong the relationship is and in what direction, and in this case reflect a strong positive correlation and a direct connection between digital gaming as a part of the learning content and the effectiveness of learning. Association measure Gamma indicates the extent to which the variation in the changing variable (T1) is explained by the changing variable (T2). Gamma coefficient 0.602 means that knowing the level of acceptance of the first statement improves the prediction of acceptance of the second statement by 60.2%. Given the substantial correlation found between these two variables and the strong correlation found between the statements provided, H_0 was confirmed.

Using correlation analysis, we examined the responses on the following statements to verify the validity of H_1: (T3) A digital game-based learning (DGBL) approach provides a dynamic and engaging learning environment (M=2.72, SD=1.309), and (T4) learning based on digital games has a positive effect on students' motivation (M=3.22, SD=1.214).

Table 2. Presentation of correlation data and the coefficient of determination for H_1

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Gamma	.640	.044	12.167	.000
	Spearman Correlation	.600	.043	13.540	.000[c]
Interval by Interval	Pearson's R	.624	.035	14.403	.000[c]
N of Valid Cases		328			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

According to Table 2's results analysis, the Chi-square test of independence demonstrates the statistical significance of the impact on the result $\chi 2(16,1) = 371.543^a$, $p<0.01$. Significance ($p \leq .05$) indicates how certain one can be that the relationship. $p<0.01$ shows that the intersection of variables is statistically significant. Spearman's rank correlation coefficient rho=0.600 and Pearson's linear correlation r = 0.624 indicate how strong the relationship is and in what direction, and in this case reflect a strong positive correlation and a direct connection between a digital game-based learning (DGBL) approach that provides a dynamic and engaging learning environment and learning based on digital games that

has a positive effect on students' motivation. Association measure Gamma indicates the extent to which the variation in the changing variable (T3) is explained by the changing variable (T4). Gamma coefficient 0.640 means that knowing the level of acceptance of the first statement improves the prediction of acceptance of the second statement by 64.0%. Given the substantial correlation found between these two variables and the strong correlation found between the statements provided, H_1 was confirmed.

Using correlation analysis, we examined the responses on the following statements to verify the validity of H_2: (T5) Digital game-based learning should include rewards, feedback, and competition (M=3.08, SD=1.305) and (T6) good information, competition, and rewarding students have a positive effect on learning outcomes (M=3.31, SD=1.070).

Table 3. *Presentation of correlation data and the coefficient of determination for H_2*

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Gamma	.510	.053	8.705	.000
	Spearman Correlation	.450	.049	9.087	.000[c]
Interval by Interval	Pearson's R	.445	.049	8.973	.000[c]
N of Valid Cases		328			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

According to Table 3's results analysis, the Chi-square test of independence demonstrates the statistical significance of the impact on the result $\chi 2(16,1) = 153.727^a$, $p<0.01$. Significance ($p \leq .05$) indicates how certain one can be that the relationship. $p<0.01$ shows that the intersection of variables is statistically significant. Spearman's rank correlation coefficient rho=0.450 and Pearson's linear correlation r=0.445 indicate how strong the relationship is and in what direction, and in this case reflect a strong positive correlation and a direct connection between the digital game-based learning (DGBL) that includes rewards, feedback, and competition and its great potential to significantly improve student learning outcomes. Association measure Gamma indicates the extent to which the variation in the changing variable (T5) is explained by the changing variable (T6). A gamma coefficient of 0.510 means that knowing the level of acceptance of the first statement improves the prediction of acceptance of the second statement by 51,0%. Given the substantial correlation found between these two variables and the strong correlation found between the statements provided, H_2 was confirmed.

Using correlation analysis, we examined the responses on the following statements to verify the validity of H_3: (T7) Digital game-based learning (DGBL) supported by artificial intelligence (AI) enables personalization (M=3.30, SD=1.117), and (T8) personalization of learning contributes to dynamically adapting learning to the performance of each student (M=3.21, SD=1.008).

Table 4. *Presentation of correlation data and the coefficient of determination for H_3*

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Gamma	.669	.048	12.092	.000
	Spearman Correlation	.577	.045	12.747	.000[c]
Interval by Interval	Pearson's R	.582	.044	12.936	.000[c]
N of Valid Cases		328			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

According to Table 4's results analysis, the Chi-square test of independence demonstrates the statistical significance of the impact on the result $\chi 2(16,1) = 216.022^{a}$, $p<0.01$. Significance ($p \leq .05$) shows how certain one can be that the relationship. $p<0.01$ indicates that the intersection of variables is statistically significant. Spearman's rank correlation coefficient rho=0.577 and Pearson's linear correlation r =0.582 indicate how strong the relationship is and in what direction, and in this case reflect a strong positive correlation and a direct connection between digital game-based learning (DGBL) supported by artificial intelligence (AI) that enables personalization and personalization of learning, which contributes to dynamically adapting learning to the performance of each student. Association measure Gamma indicates the extent to which the variation in the changing variable (T7) is explained by the changing variable (T8). Gamma coefficient 0.669 means that knowing the level of acceptance of the first statement improves the prediction of acceptance of the second statement by 66.9%. Given the substantial correlation found between these two variables and the strong correlation found between the statements provided, H_3 was confirmed.

Discussions

In recent years, digital learning games have emerged as an established practice in the field of education. With the greater understanding of gaming that young people today possess, educators can design engaging learning environments to increase student interest. Drawing students' attention is one of the main benefits of DGBL in the classroom. Students are thus encouraged to actively engage in their education, in contrast to textbooks and conventional classroom instruction, which are occasionally insufficiently compelling to grab and hold students' attention. DGBL methods provide instant feedback on the choices students make while playing games, in contrast to traditional ways of testing and verifying students' knowledge for evaluation by their instructors. In this way, students are able to improve their problem-solving abilities almost immediately by learning from their failures in real time. Additionally, DGBL promotes cooperation among participants since social contact rises when students collaborate to solve game difficulties or when they compete against other student groups. Communication, cooperation, teamwork, and social interaction can all contribute to deeper learning, which in turn can improve grades and test scores. DGBL can be used for purposes other than schooling, it speeds up the effects of healthcare, civic participation, and staff training (Sharma, 2023). Thanks to DGBL, students from many countries are working together on projects and learning about each other's cultural perspectives, which is increasing the appeal of global collaboration. This creates an inclusive, multicultural classroom that broadens students' horizons and increases their awareness of the world (Paradisosolutions, 2025).

However, depending on the individual learning style of each student or the educator's approach to teaching, there may be drawbacks to learning through digital games. These negative aspects include the fact that students spend excessive amounts of time in front of computers. Playing games can disrupt their other daily activities, and digital games aren't always in line with the objectives of their studies. Finally, students may be exposed to possible threats to their cybersecurity through DGBL. To obtain unauthorized access, cybercriminals frequently employ techniques like password cracking and security vulnerability exploitation. Proper student engagement and learning outcomes are obviously impacted by this. Phishing schemes in-game frequently take the shape of emails that appear authentic and deceive gamers into divulging personal information or login credentials. Additionally, social engineering in games refers to coercing users into disclosing private information or taking activities that jeopardize their security (Cooper, 2024).

The ongoing integration of cutting-edge digital technology (such as artificial intelligence and immersive technologies) is what DGBL's future holds. AI-enhanced virtual worlds and more complex 3D games create new opportunities for individualized, interesting, and successful education. With technology greatly influencing how students learn, the future of DGBL is becoming very interesting. AI-driven personalization is one of the most exciting developments. It allows learning to adjust in real time to each student's performance and preferred method of learning, generating dynamic learning routes that suit each student's needs, increasing learning engagement, and enhancing retention as it goes (Paradisosolutions, 2025). The current study suggests that when learning is personalized using AI, students are more likely to identify their own abilities and inventiveness (Baltezarević and Baltezarević, 2024).

Participants provided their attitudes, for the study's purposes, about the effects of digital game-based learning (DGBL) on students' academic performance. According to the results, students are more likely to improve their learning efficiency when they combine educational content with digital games.

This is in line with earlier research showing that digital gaming affects young people's social behavior and academic achievement (Rahayu, 2021). Additionally, DGBL combines instructional information with digital games to attract students' interest and provide them with opportunities to enhance their learning effectiveness. As a result, students have a positive outlook on learning and information for the rest of their lives (Cheng et al., 2013). The study also shows that if a DGBL strategy provides a dynamic and engaging learning environment, it is more likely to boost student motivation and involvement in the learning environment. This outcome is consistent with research by Li et al. which demonstrated that students who played educational digital games were more motivated to learn. Consequently, it is possible to consider these games as "stimuli" that could increase students' learning motivation (Li et al., 2024). The next finding of this study, that DGBL, which includes rewards, feedback, and competition, has greater potential to significantly improve student learning outcomes, finds its basis in the finding of Chen et al. They claim that DGBL provides students with challenging, dynamic, and captivating learning environments that significantly boost students' motivation and involvement in the learning process by implementing competitive processes, accomplishment systems, and reward mechanisms (Chen et al., 2018). Regarding the result, according to whom artificial intelligence (AI) that facilitates personalization through digital game-based learning (DGBL) increases the likelihood that the learning will dynamically adjust to each student's performance. This supports a previous study by Westera et al. that discovered AI applications can improve game-based learning's adaptability. Game design aspects that facilitate learning encompass a variety of AI-based features, including social gamification, language technologies, emotional computing, competence modeling, evaluation, player analytics, personalization, and game difficulty balancing (Westera et al., 2020). There is a connection between this remark and the assertion made by Parody et al. that this personalized approach may significantly increase motivation and engagement, two crucial elements of successful gamification (Parody et al., 2022).

Conclusions

The aim of this study was to investigate participants' perspectives on the effects of digital game-based learning (DGBL) on students' academic performance for the purpose of gathering information that will assist educators, lawmakers, game designers, and artificial intelligence developers in improving the educational role of digital games in order to enhance student achievement. According to this study, participants believe that DGBL can increase student learning efficiency and that such a dynamic and engaging learning environment can increase their motivation and participation. If DGBL includes rewards, feedback, and competition, it can further improve student learning outcomes. Finally, if DGBL is supported by AI, personalization can be enabled, and in this way, learning may be dynamically adapted to each student's performance. The DGBL approach is currently in its initial phases of application; therefore, more time is required for its continued development and adaptation. Moreover, all current obstacles must be rectified before this approach may realize its full potential. Additional studies would also more thoroughly analyze how DGBL affects students and instructors as well as the educational sector as a whole, providing a better grasp of all the benefits and drawbacks of these methods of instruction. With a solid basis for further research and real-world applications, this study contributes notably to the fields of educational technology, artificial intelligence (AI), and immersive technologies (which are known as augmented reality (AR) and virtual reality (VR)). Additional research involving other respondent demographics, implementation and evaluation techniques could broaden the conclusions of this empirical study.

Based on our results, we suggest that future studies thoroughly examine the function of immersive technologies in DGBL, paying special attention to the potential applications of the latest technology that can arouse students' senses in an augmented or virtual reality setting (e.g., haptic gloves and suits). This would increase students' involvement, interest, and motivation for learning while reducing the sense that they are not a part of the virtual environment. Under these virtual circumstances, students can visit museums or well-known historical locations, work on group projects, or carry out difficult tasks (like practicing virtual surgery in authentic settings). In any event, this virtual experience makes learning more memorable, efficient, and enjoyable.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, B.R., and B.I.; methodology, B.R.; software, B.R.; formal analysis, B.R.; writing—original draft preparation, B.R. and B.I.; writing—review and editing, B.R. and B.I. All authors have read and agreed to the published version of the manuscript.

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Personality Predictors of Flourishing and Learning to Flourish

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Abstract: Given the abundance of research on well-being and flourishing, this study aimed to outline the direct and indirect effects of personality predictors on flourishing. The cross-sectional study included ten scales, measuring personality traits (the extraversion, neuroticism, openness to experience, consciousness, agreeableness and the meta-traits of plasticity and stability) and personal dispositions (self-esteem, mindfulness, coping and coping potential, learned helplessness, self-handicapping, planning, and rumination) and a convenient sample of 451 respondents. A ten-session training designed to promote flourishing was conducted with 10 participants over a three-month period. Results revealed a stronger direct effect of personal dispositions than personality traits, as well as a moderating effect of personality traits and a mediating effect of dispositions. Flourishing is predicted by high self-esteem, proactive coping, mindfulness, agreeableness, and meaning in life. Problem-oriented coping mediates the relation of agreeableness and flourishing. Conscientiousness and stability moderate the relation of proactive coping and mind-fulness with flourishing, and plasticity moderates the relation of self-esteem and flourishing. This finding is considered to highlight the specific role of plasticity and stability both as traits and dispositions, related to self-regulation. Self-esteem needs to be flexible enough to be revised and validated and is supported by plasticity, while proactive coping and mindfulness, as dispositions related to cognitive, emotional, and behavioral aspects, are supported by stability. Flourishing is predicted to a greater extent by behavioural patterns than by personality traits, and the pathways to flourishing can be learned, which is of particular interest for integration in education as proactive support for individual performance, especially in times of crisis and instability.

Keywords: *flourishing, personality traits, mindfulness, coping.*

Introduction

This study seeks to answer two questions: how personality traits and dispositions predict flourisxing and the role of proactive learning in flourishing. These points are outlined within the broad perspective of well-being in flourishing research. At the core of positive psychology is a shift in focus to individual strengths and their relationship to self-efficacy and well-being (Seligman, 2011). The study of well-being is generally described by several research perspectives, the hedonic - positive affect and life satisfaction, happiness and the eudaemonic - psychological well-being (self-acceptance, life purpose, autonomy, environmental mastery, positive relationships with others, personal growth). Another suggestion for study of well-being is in the domains of happiness and satisfaction with life, mental and physical health, meaning and purpose, character and virtue, close social relationships, financial and material stability (VanderWeele, 2017). A relatively new perspective is the concept of flourishing. Flourishing has been proposed as a comprehensive and integrative theoretical framework for understanding well-being that encompasses subjective, psychological, and social well-being and refers to the optimal level of experienced well-being (Diener et al., 2010; Seligman, 2011; Huppert and So, 2013) and is commonly used to describe the experience of high well-being (Diener et al., 2010; Hone et al., 2014; Seligman, 2018; Burns et al., 2025). Keyes (2007) suggests the two continua model of mental health and illness and discusses benefits of flourishing for individuals and society. Turecek et al. (2024) divide flourishing and thriving, however refer to more similarities than differences of flourishing and thriving individuals. Individuals who score high on flourishing and thriving have better behavior regulation strategies and higher levels of positive affect and positive

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relationships, mental and physical health (Turecek et al., 2024) and connection to something larger than the self (Seligman, 2011). According to VanderWeele (2017), flourishing is associated with optimal functioning in five broad domains: (i) happiness and life satisfaction; (ii) health, both mental and physical; (iii) meaning and purpose; (iv) character and virtue; and (v) close social relationships across two criteria: as a desirable goal and as universally desirable goals, considering not only the present moment but also in a temporal perspective - a perceived secure environment, including financial and social stability, in order to flourish over time (VanderWeele, 2017).

Flourishing is considered to be a multidimensional concept. Numerous cross-cultural comparisons have been conducted, as well as qualitative research on respondents' perceptions and what they believe they need to flourish, and various studies have ranked social support, stable income, and social determinants of health as the most important factors; meaningful work, identity, and family are also widely ranked by respondents. The wide range of responses and included domains leads to the suggestion well-being and flourishing to be viewed as multidimensional constructs (Burns et al., 2025). In a similar direction is the proposed expansion of the concept of positive well-being, accounting for relationship, parenting, and employment, which are reported to have more significant effect on well-being than age, gender, or income (Brydges et al., 2025).

Today, there is a growing discussion about the diversity of approaches to studying the concept of flourishing and its implications. There are several models of flourishing that have been proposed and are commonly cited in the literature, having both similarities and differences (VanderWeele, 2017). Novak et al. (2024) discuss the increased interest in flourishing in recent years and analyze the instruments that measure flourishing, concluding that despite obvious structural similarities, flourishing instruments have significant differences at the component and item level, which suggest future consensus among researchers on what flourishing really entails (Novak et al., 2024). The same position regarding the different forms and aspects of well-being research is supported by other researchers. The main question concerns the concept of overall well-being and the well-being sustainability across a number of balanced and harmonized systems e.g. personality dimensions, self and others, people and environment, and time (Lomas et al., 2024).

In this study flourishing is considered within the PERMA model, which includes positive emotions, engagement, relationships, meaning, and accomplishments (Seligman, 2011). For each of these flourishing domains there is a large body of research on their relevance to well-being. Positive emotions are reported to support well-being and furthermore, can be cultivated over time (Fredrickson, 2001). Positive emotions lead to better physical and mental health (Fredrickson and Levenson, 1998; Danner et al., 2001) and stimulate physical, intellectual, social, and psychological resources (Fredrickson et al., 2003). Engagement is related to flow theory (Csikszentmihalyi, 1990) and is associated with higher levels of happiness, fewer depressive states (Seligman et al., 2005), and greater life satisfaction (Peterson et al., 2005). Positive relationships with others are strongly associated with well-being (Seligman, 2012) and better personal performance (Gable et al., 2004; Diener and Biswas-Diener, 2008; Fowler and Christakis, 2008; Tay et al., 2012). Meaning in life is confirmed as an antecedent of better health and higher satisfaction with life (Steger, 2012). Achievements facilitate psychological well-being (Brunstein, 1993), especially the achievement of internal goals, as well as perceived accomplishments (Seligman, 2012). Personality predictors – personality traits and personal dispositions – are related to flourishing.

Personality traits from the Big Five model have been reported to be significant predictors of well-being (McCrae and Costa, 1991; DeNeve and Cooper, 1998; Mann et al., 2021). For personal dispositions, there is evidence that coping is related to well-being (Otero-López et al., 2021), especially active (Lee et al., 2019), assimilative and accommodative coping (Brennan-Ing et al., 2013; Arends et al., 2016), and coping potential (Smith and Kirby, 2009). In this study, we also consider ineffective coping in terms of adaptive and ineffective behavioral models, specifically learned helplessness, self-handicapping, rumination, and planning. Learned helplessness represents passive behaviour and an inability to learn when faced with stressful, uncontrollable, and unavoidable adverse events, triggered by the automatic defensive transfer of negative past experiences (Seligman and Maier, 1967; Elliott and Dweck, 1988; Dweck and Yeager, 2019). Self-handicapping is related to motivation theory (Atkinson, 1964; Greenberg, 1985) and is viewed as an anticipatory defense aimed at protecting oneself and self-esteem in the face of possible adverse developments (Jones and Berglas, 1978). Despite the different approaches to mindfulness, it has also been shown to be a predictor of well-being (Brown and Ryan, 2003; Baer et al., 2004; Carson et al., 2004; Grossman et al., 2004; Carmody and Baer, 2008, Giluk, 2009; Jones et al., 2011; Eberth and Sedlmeier, 2012; Hanley and Garland, 2017). In practical terms the benefits of mindfulness, reported in

various therapeutic approaches (Kabat-Zinn, 1994; Segal et al., 2002; Grossman et al., 2004) reveal its relation to self-regulation and adaptive potential. Research confirms the positive relations of mindfulness with well-being and the Big Five (Brown and Ryan, 2003; Giluk, 2009; Stahl and Goldstein, 2010; Bergen-Cico et al., 2013; Rizer et al., 2016; Hanley and Garland, 2017; Ortet et al., 2020). Self-esteem has a specific role in personal adjustment and better performance (Diener and Diener, 1995; DeNeve and Cooper, 1998; Oishi et al., 1999) and is also related to the Big 5 (Robins et al., 2001; Varanarasama et al., 2019) and well-being (Sowislo and Orth, 2013). Studies demonstrate that meaning in life and search for meaning predict happiness (Park et al., 2010; Steger et al., 2014), positive emotions, self-esteem, optimism, life satisfaction (Ryff, 1989; Compton et al., 1996; King et al., 2006; Steger et al., 2009), and well-being (Zika and Chamberlain, 1992; Ryff and Keyes, 1995). Meaning in life is an important part of psychological well-being (Mascaro and Rosen, 2005; King et al., 2006; Steger et al., 2006). Search for meaning is conceptualized differently - as inner process with positive correlation with psychological well-being (Ryff, 1989) and as a deficit need in the case of frustration (Baumeister, 1991; Klinger, 1998).

With respect to learning to flourish, evidence for pathways to promoting well-being and flourishing is highlighted. Conclusions reveal that variety of positive experiences and feelings is another important dimension that enhances subjective well-being, flourishing, resilience, and prevents hedonic adaptation (Brydges et al., 2025). The broaden-and-build theory describes the way, in which positive emotions can broaden individual's thought-action repertoire (Fredrickson, 2001) and form a self-reinforcing cycle of upward spiral of positivity (Fredrickson and Branigan, 2005). Recently, during the pandemic, a variety of not only interventions but also educational approaches have been implemented to support individual flourishing by the means of training in well-being skills, mobile app-based mindfulness interventions, academic courses in the philosophy of happiness (Colaianne et al., 2025). This is in line with the plenty of research on learning coping strategies and behavioural patterns, targeting well-being and flourishing in long term.

Materials and Methods

Aim and hypotheses of the study

The aim of this study was to examine the direct, mediated, and moderating effects of personality traits and dispositions on flourishing and the opportunities for enhancing personal resources to achieve optimal self-regulation (Fig. 1) and has four hypotheses:

H_1: Personality traits will predict flourishing with low to moderate effect

H_2: Personal dispositions will predict flourishing with higher direct effect compared to personality traits

H_3: Personality traits and personal dispositions will have direct, mediated, and moderated effects on flourishing

H_4: Training, devoted to enhancement of personal potential for self-regulation will have effect on flourishing predictors and flourishing

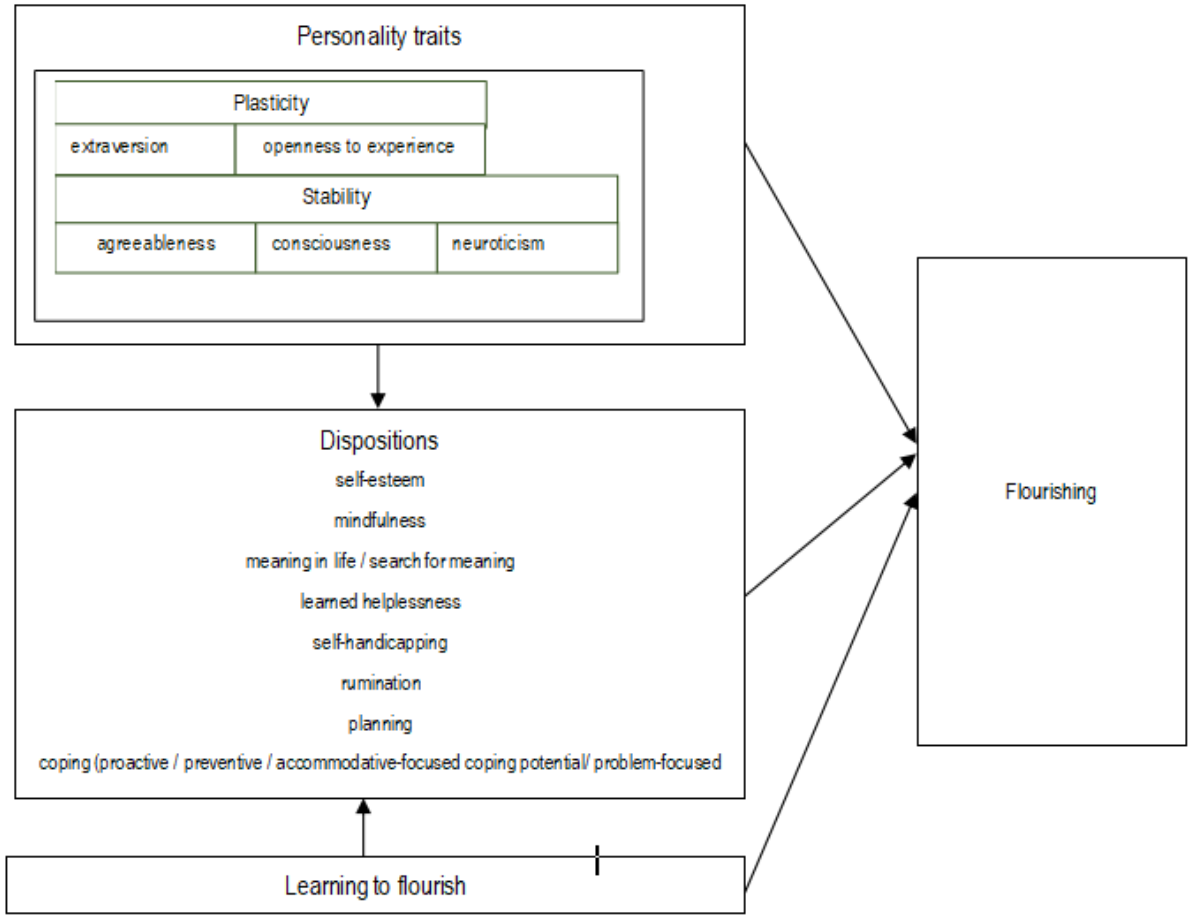

Figure 1. Research model

Scales

Ten scales were administered, all with a 5-point Likert response scale (1 = strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, 5 = strongly agree). All scales had been adapted, with three direct translations and one back-translation and psychometric properties validated for each scale used (component analysis and reliability). The scales include 1) The *Meaning in Life Questionnaire* (MLQ) (Steger et al., 2006) - a 10-item scale that forms two subscales for meaning in life (α = . 885) and search for meaning in life (α = .898), each one comprising 5 items. 2) The *Planning scale* – a 10-item scale created for the purpose of the study The items were selected with an expert panel from a pool of 30 items, following the long- and short-term planning model (Lynch et al., 2009; Steinberg et al., 2009). Two subscales are formed (each of 5 items), measuring planning as important (α = .636) and as unimportant (α = .624). 3) The *Mistake Rumination Scale* (Flett et al., 2020), a 7-item unidimensional scale (α = .838). 4) The 25-items *Self-Handicapping Scale* (Rhodewalt, 1990) (α = .775). 5) The *Learned Helplessness Scale* (LHS) (Quinless and Nelson, 1988) 20-items scale (α = .933). 6) The *Rosenberg's Self-Esteem Scale* (Rosenberg, 1965) 10-item scale designed to measure global self-esteem (α = .821). 7) The *Cognitive and Affective Mindfulness Scale* - Revised (CAMS-R) (Feldman et al., 2007) 10-item scale (α = .863). 8) Coping was measured with two subscales for proactive and preventive coping and two subscales for accommodative and problem-focused coping potential. The proactive and preventive coping subscales are derived from the 55-item Proactive Coping Inventory (PCI): A Multidimensional Research Instrument (Greenglass et al., 1999). The *proactive copying subscale* contains 14 items (α = .893), and the *preventive copying subscale* contains 10 items (α = .846). *Coping potential* was measured as *accommodative-focused coping potential* (α = .903) and *problem-focused coping potential* (α = .927) scales that include 12 items each one (McLain, 2012). 9) The *Big Five Inventory* (BFI-2) (Soto and John, 2017) 30-items scale, having 6 items for each of the five personality traits *Extraversion (*α = .733*); Agreeableness (*α = .613*);*

*Conscientiousness (*α = .731*); Neuroticism* with 1 item removed *(*α = .780*); Openness to Experience* with 1 item removed *(*α = .687). 10) The 8-items *Flourishing Scale* (Diener et al., 2009) (α = .908).

Procedure and Participants

The survey to test H1-H3 was conducted online through the survs.com platform between January 2021 and December 2022. 2,000 invitations were sent and 493 fully completed forms were received. After removing outliers, responses from 455 individuals were used for data analysis (Table 1).

Table 1. *Distribution of respondents*

					Total
Gender	women	men			455
	300 (66%)	155 (34%)			
Age	below 25 years	25-35 years	above 35 years		455
	105 (23%)	152 (33%)	198 (44%)		
Family status – living	Alone	With partner	With family	Prefer not to answer	455
	65 (14%)	97 (21%)	243 (54%)	50 (11%)	
Occupation	only study	only work	work and study	neither work nor study	455
	94 (21%)	55 (12%)	256 (56%)	50 (11%)	
Subjective assessment of incomes	sufficient to cover their needs	insufficient to cover their needs	unwilling to answer		455
	218 (48%)	150 (33%)	87 (19%)		

To test H4, a control group and an experimental group were formed. The training was carried out in the period April 2022 - December 2022. The training consisted of 10 sessions over a period of 3 months. The results were compared within the experimental group and between the experimental and control groups at three points in time, before and after the training and 6 months after the completion of the training. The expectation was that the training would improve measured performance. The design included measures of personal dispositions before and after training as proximal outcomes and the flourishing indicator as a distal outcome. To test this hypothesis, we assessed outcomes before training (T1), after training (T2), and six months after training (T3). Participants were recruited by invitation to undergraduate humanities students. After students agreed to participate, they were directed to a pre-test survey. All surveys were administered electronically using the survs.com platform. Scales from the main survey were used, with the exception of the Big Five inventory. Personality traits were not included as a scale because no change in them was expected as a distal outcome.

The idea of the training was to examine whether learning alone, delivered to students without reported need or search for support, will be beneficial. In order to form the experimental and control groups, the recruitment was done in two steps to ensure equality and an initial good level of performance. All 73 undergraduate students of a bachelor programme were invited to participate in a training session and 20 of them expressed interest. All 73 students were administered the pre-training scales. The equality of the control and experimental groups prior to the training was ensured by selecting respondents who were willing to participate in the training and those who were not, with levels of perceived flourishing, meaning in life, mindfulness, proactive coping above the theoretical mean of the scales, and defensive behaviours below the theoretical mean of the scales, without significant differences between the control and experimental groups. This led to a reduction in the number of participants for the training to 13. After dropouts in T2 and T3, each group had 10 participants in T3 (Table 2).

Table 2. *Description of the participants in the control and experimental group*

	T1 March 2022 (N)	T2 June 2022 (N)	T3 December 2022 (N)
Control group	20	11	10
Experimental group	13	11	10

The training design included expressive techniques and discussions focused on self-reflection. The ten sessions were delivered over a 3-month period and each session lasted two hours. The topics of the sessions were: creating a safe and secure environment; strengthening sense of self and identity; accepting uncertainty; building assertiveness and strengthening self-esteem; making sense of relationships - self and others; psychological intimacy; motivation and goals; stress management; self-expression; well-being. The training framework was based on stability and plasticity meta-traits, suggested in the cybernetic theory (DeYoung, 2006, 2105), extrapolated as two lines of personal functioning, having research and practical potential towards describing and promoting effective behaviours. The design of the training was based on Seligman's Flourishing Model (Seligman, 2011) and Appraisal Theory (Smith and Kirby, 2009, 2011). Evidence for effective and lasting change toward improved personality traits (Steger et al., 2021), the role of phototherapy in increasing meaning in life, life satisfaction, and positive affect, and decreasing negative affect (Steger et al., 2014) were also considered in the design. The overall goal was to promote a proactive mindset - because for the proactive person, coping is not a singular response, but a consistent pattern of behavior (Schwarzer, 1999).

Data Analysis

Data were processed using IBM SPSS Statistics 25 and Process v.3. The steps of the analysis were principal component analysis with rotation and reliability test using Cronbach's alpha and item analysis, descriptive statistics, Kolmogorov-Smirnov test, analysis of variance, correlation analysis followed by direct linear effects of personal dispositions, regression models for the effect of Big Five on flourishing and personal dispositions and of personal dispositions of flourishing and general regression models including all personality traits and personal dispositions. Afterwards the mediating role of personal dispositions was examined, and the moderating effect of personality traits was sought for personal dispositions with an independent effect. Mediators and moderators were selected based on reported relationships and predictor models for personality traits and personal dispositions for flourishing and personality traits for personal dispositions. Comparisons between the control and experimental groups were made using t-tests. All outliers were removed. All variables were within the acceptable range of kurtosis and skewness - from -2 to +2. When necessary, a correction for normalization was made, using the logarithmic transformation, despite the prevalence of non-normal data, especially in social sciences (Blanca et al., 2013). Standard rules were followed for component and reliability analysis (Boateng et al., 2018; Moretti et al., 2019). For all scales Cattell's scree plot and an exploration analysis by principal components method with Varimax rotation was performed with Kaiser-Meier-Olkin test for overall sample adequacy - KMO value > .600; valid result of the Bartlett's test of sphericity to test correlations between variables (accepted criterion for significance is $p < .01$); generated factor model explaining 50% of the total variance given extracted factors with eigenvalue > 1.0 (Kaiser normalization criterion) and given the sample size value of the factor weight >.400 (in view to the conservative criterion of including in the pattern-matrix only items with factor weights of .600 and values depending on the sample size). In terms of reliability the value of Cronbach's alpha was > .700 (with adjustment for brief scales of .600); the correlation between individual items and the whole scale was greater than .400 (using the Spearman-Brown prediction formula). For regression adding additional predictors that explain a significant amount of additional variance for the criterion, with an inclusion criterion of $p = .1$. All regression analyses had 95% confidence intervals, collinearity and prescreening for outliers was performed. For the mediation analysis, a preliminary screening of the data for assumptions of univariate normality was performed with determination of skewness and kurtosis of distribution below the acceptable threshold for excess (±2) and (±7) for kurtosis (Hair et al., 2010). Screening for outliers was also performed using Cook's distance and no potential outliers were detected (they were removed at the stage of checking the validity and reliability of the scales). The mediation analysis followed the standard steps - 1) the independent variable to have a significant relationship with the dependent

variable; 2) the independent variable to have a relationship with the putative mediators; 3) the mediator to have a significant relationship with the dependent variable; 4) when controlling for the mediator, there must be a significant change in the effect of the independent variable (Baron and Kenny, 1986) for full and partial mediation. The total effect and unstandardized coefficients were reported (Preacher and Kelley, 2011; Edwards, 2013) as if the value 0 does not fall within the confidence interval generated to determine the significance of the mediated effect, it is concluded that the indirect effect of the independent variable on the dependent variable through the relevant mediator is significant. Moderation analysis followed the requirement variations in the level of the independent variable to cause significant variations in the level of the mediator variable (path "a"); variations in the mediator variable to cause significant variations in the dependent variable (path "b"); when path 'a' and path 'b' are controlled, the total effect of the independent on the dependent variable (path 'c') to differ from the measured direct effect of the independent variable on the dependent variable (path 'c') by a residual, which is denoted by the equation c = c' + ab, where the product 'ab' calculates the indirect effect of the independent variable on the dependent variable.

Results

Individual variables and correlations

The individual variables of marital status, age, gender, subjective assessment of income, and occupational status (work/study, study and work, and neither study nor work) had partial individual effects on flourishing and were not reported as independent predictors in the regression models, nor as moderators of the relationships between personality traits and dispositions and well-being. The total variance in flourishing accounted for by the aggregate effect of the individual variables is small (R2 = 0.090). Among the individual effects, higher flourishing is experienced by people who are professionally and developmentally engaged, who rate their income as sufficient to meet their needs, and who are over 35 years of age. There were moderate positive partial correlations between flourishing and the personality traits and meta-traits ($r(455) = .389$ to .526; $p < .001$). Personality traits had low and moderate positive correlations with self-esteem, meaning in life, planning, mindfulness, and coping ($r(451) = .331$ to .583; $p < .001$) and low to moderate negative correlations with learned helplessness, self-handicapping, rumination, and search for meaning ($r(451) = -.169$ to -.447; $p < .05$). Self-esteem had low to moderate positive correlations with meaning in life, planning, mindfulness; coping ($r(451) = .263$ to .618; $p < .001$) and negative with search for meaning, learned helplessness, self-handicapping and rumination ($r(451) = -.306$ to -507; $p < .001$). Meaning in life had low to moderate positive correlations with planning, mindfulness, coping ($r(451) = .269$ to .634 ; $p < .001$) and negative with search for meaning, learned helplessness, self-handicapping and rumination ($r(451) = -.333$ to -.468; $p < .001$). Search for meaning was moderately positively related to learned helplessness and self-handicapping ($r(451) = .297$ to .316) and low negative correlation with accommodative coping ($r(451) = -.175$; $p < .001$). Planning had low positive correlations with the four coping variables ($r(451) = .139$; $p < .001$) and negative with learned helplessness and self-handicapping ($r(451) = -.182$; $p < .001$). Mindfulness had moderate to high positive correlations with the four coping variables, self-esteem and meaning in life ($r(451) = .338$ to .705; $p < .001$) and negative with learned helplessness, self-handicapping, and rumination ($r(451) = -.194$ to -.482; $p < .001$). Rumination had moderate positive correlations with self-handicapping and learned helplessness ($r(451) = .505$ to .558; $p < .001$) and negative with coping variables ($r(451) = -.324$ to -.505; $p < .001$). Self-handicapping and learned helplessness had moderate positive correlation ($r(451) = .599$) and negative correlations with proactive, preventive, accommodative and problem-focused coping ($r(451) = -.169$ to -.507; $p < .001$). Coping scales had moderate to high positive correlations ($r(451) = .402$ to .802; $p < .001$). Proactive coping had moderate positive correlations with self-esteem, meaning in life, and mindfulness ($r(451) = .582$ to .622; $p < .001$) and negative with self-handicapping and learned helplessness ($r(451) = -.412$ to -.508; $p < .001$). Preventive coping had low to moderate positive correlations with self-esteem, meaning in life, and mindfulness ($r(451) = .263$ to .491; $p < .001$) and negative with self-handicapping and learned helplessness ($r(451) = -.139$; $p < .001$). Accommodative coping had moderate positive correlations with self-esteem, meaning in life, and mindfulness ($r(451) = .382$ to .705; $p < .001$) and negative with self-handicapping and learned helplessness ($r(451) = -.221$ to -.653; $p < .001$). Problem-oriented coping had moderate positive correla-

tions with self-esteem, meaning in life, and mindfulness (r(451) = .489 to .668; p < .001) and negative with self-handicapping and learned helplessness (r(451) = -.386 to -.599; p < .001).

Regression analyses, moderation and mediation

The model of personality traits with the highest explanatory power for flourishing (R^2 = .373 Durbin-Watson = 1,950; F = 31,488; p = .001) outlined as individual predictors agreeableness (ß = .247), extraversion (ß = .232), consciousness (ß = .190), and neuroticism (ß = -.219). After adding the meta-traits independent effect was accounted for plasticity (ß = .349), agreeableness (ß = .263), and neuroticism (ß = -.241), however the total variance explained by the model was lower (R^2 = .310; Durbin-Watson = 1.731; F = 37.45; p = .001). The meta-traits model predicting flourishing (R^2 = .352; DW = 1.747; F = 62.42) accounted independent effect of plasticity (ß = .305) and stability (ß = .416). The model of personal dispositions (R^2 = .672; Durbin-Watson = 1,856; F = 93,79; p = .001) outlined as predictors having direct effect self-esteem (ß = .299), proactive coping (ß = .265), mindfulness (ß = .233), and meaning in life (ß = .208). The general regression model, including personality traits and dispositions revealed model with the highest explanatory power (68%) with individual predictors self-esteem (ß =.275), proactive coping (ß =.270), mindfulness (ß = .220), agreeableness (ß = .138), and meaning in life (ß = .131) (R^2 = 0,682; DW = 1.859; F = 97.75; p = .001). problem-focused coping mediated the effect of agreeableness on flourishing and consciousness, stability and plasticity moderated the positive effect of self-esteem, proactive coping, and mindfulness on flourishing.

Concerning mediating effect of problem-focused coping potential agreeableness had direct and indirect effect on flourishing. The direct effect of agreeableness on problem-oriented coping potential was positive and significant (b = .4131; s.e. = .0691; p = .00. [.2769; .5493] with an explained variance of 14%. The direct effect of problem-oriented coping potential on flourishing was positive and significant (b = .7406; s.e. = .0561; p = .00. [.6301; .8511]. The direct effect of agreeableness on flourishing was positive and significant (b = .2631; s.e. = .0626; p = .00. [.1398; .3864]. With R^2 = .1939 and F = 54.12; df = 453 (p = .001), the model was significant. Agreeableness was significantly positively related to flourishing with regression coefficient b = .5691; se = .0774; p = .000 [LLCI = .4166; ULCI = .7215]. The indirect effect of agreeableness on flourishing, mediated by problem-focused coping potential on flourishing was positive and significant (b = .3059; se = .0768 [.1611; .4612]. The direct effect of agreeableness on flourishing remained significant (b = .2631; s.e. = .0626; p = .000. [.1398; .3864], indicating that problem-focused coping potential partially mediated the relation of agreeableness and flourishing. Higher problem-focused copying potential increased the positive effect of agreeableness. The effect of proactive coping, self-esteem and mindfulness on flourishing was moderated by consciousness, stability and plasticity. Plasticity moderated the relation of self-esteem and flourishing, and stability moderated the relation of proactive coping and mindfulness with flourishing. All indirect effects were positive at any value of the predictor. An increase in consciousness increased the positive effect of proactive coping and mindfulness on flourishing. Increase of plasticity increased the relation of self-esteem and flourishing. Proactive coping and mindfulness predicted high flourishing, which increased as stability increased (Table 3).

Table 3. *Moderating effects of consciousness, plasticity, and stability*

	coeff	se	t	p	LLCI	ULCI
constant	-2.6576	.8724	-3,0460	.026	-4.3765	-.9381
proactive coping	1.5577	.2293	6.7946	.000	1,1059	2,0095
consciousness	.0522	.2442	4.3096	.000	.5711	1.5333
proactive coping * consciousness	- .2280	.0621	-3.6715	.003	-.3504	-.1056
conditional effects of the predictor at values of the moderator consciousness						
3,17	.8357	.0624	13,0595	.0000	.7126	.9587
3.83	.6836	.0592	11,1975	.0000	.5669	.8004
4.50	.5316	.0809	6.9425	.0000	.3721	.6911
R^2 = .5610; MSE = .2010; F = 94.99; df1 = 3; df2 = 451; p = .000; X*W R^2-chng = .0265; F = 13.48; p = .0003						
	coeff	se	t	p	LLCI	ULCI
constant	-2.6008	.7856	-3.3104	.0011	-1,1489	-1,0527
mindfulness	1.6483	.2187	7.5364	.0000	1.2173	2,0793
consciousness	1,1978	.2225	5.3838	.0000	.7594	1.6363
mindfulness * consciousness	-.2834	.595	-4.7607	.0000	-.4007	-.1661
conditional effects of the predictor at values of the moderator consciousness						
3,17	.7509	.0589	12.75	.0000	.6349	.8670
3.83	.5620	.0564	9.96	.0000	.4508	.6732
4.50	.3731	.0778	4.80	.0000	.2198	.5263
R^2 = .7335; MSE = .2116 ; F = 86.55; df1 = 3; df2 = 451; p = .000; X*W R^2-chng = .0470; F = 22.66; p = .000						
	coeff	se	t	p	LLCI	ULCI
constant	-2.7748	1,1864	-2.34	.0202	-5,1127	-.4369
self-esteem	1.6241	.3180	5,11	.0000	.9975	2.2508
plasticity	1,1631	.3360	3.46	.0006	.5009	1.8252
self-esteem * plasticity	-.2536	.0879	-2.89	.0043	-.4268	-.0804
conditional effects of the predictor at values of the moderator plasticity						
3,08	.8423	.0699	12,04	.0000	.7044	.9801
3.67	.6943	.0566	12.26	.0000	.5827	.8059
4,17	.5676	.0771	7.36	.0000	.4156	.7195
R^2 = .5555; MSE = .2035; F = 92.91; df1 = 3; df2 = 451; p = .000; X*W R^2-chng = .0166; F = 8.33; p = .0043						
	coeff	se	t	p	LLCI	ULCI
constant	-4.6060	1.3703	-3.36	.0009	-7.3064	-1.9056
proactive coping	1.8677	.3542	5.27	.0000	1,1696	2.5658
stability	1.6600	.3910	4.25	.0000	.8894	2.4306
proactive coping * stability	-.3285	.0990	-3.32	.0011	-.5236	-.1335
conditional effects of the predictor at values of the moderator stability						
3,17	.8272	.0666	12.42	.0000	.6959	.9585
3.61	.6810	.0564	12.07	.0000	.5699	.7921
4,06	.5353	.0761	7.04	.0000	.3854	.6853
R^2 = .5908; MSE = .1874; F = 107; df1 = 3; df2 = 451; p = .000; X*W R^2-chng = .0202; F = 11,02; p = .0011						
	coeff	se	t	p	LLCI	ULCI
constant	-3.5725	1.2625	-2.8296	.0051	-6,0605	-1,0845
mindfulness	1.6817	.3417	4.9216	.0000	1.0083	2.3550
stability	1.5508	3.3676	4.2191	.0000	.8265	2.2752
mindfulness * stability	-.3137	.0970	-3.2340	.0014	-.5048	-.1225
conditional effects of the predictor at values of the moderator stability						
3,16	.6881	.0621	11.08	.0000	.5657	.8105
3.61	.5485	.0559	9.82	.0000	.4384	.6586
4,06	.4094	.0781	5.25	.0000	.2556	.5632
R^2 = .5415; MSE = .2100; F = 87.78; df1 = 3; df2 = 451; p = .000; X*W R^2-chng = .0215; F = 1.46; p = .0014						

In the general model, flourishing was predicted by high self-esteem, proactive coping, mindfulness, agreeableness and meaning in life. Problem-oriented coping potential mediated the relationship between

agreeableness and flourishing. Conscientiousness and stability moderated the relationship between proactive coping and mindfulness with flourishing, and plasticity moderated the relationship between self-esteem and flourishing (Fig. 2).

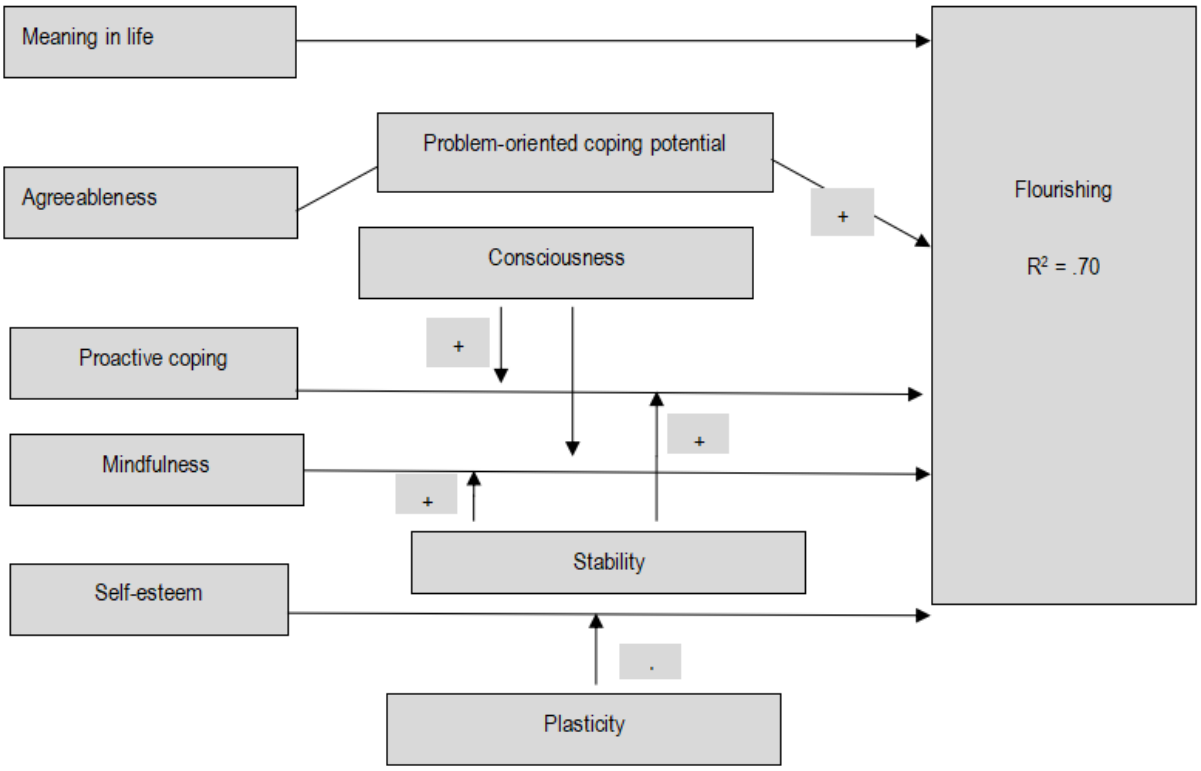

Figure 2. General model of flourishing

Effect and sustainability of the training

In accordance with the design of the piloted training, the results were examined with a comparison between the control and experimental groups before the training, after the training and six months later. The comparison between the control and experimental group after the training is analogous with the results after six months. Significant difference with large effect size ($t = 2.4507$; $p < .05$; $d = 1.10$) for all participants was reported only for meaning in life (control group $M = 3.80$; $SD = .836$; experimental group $M = 4.60$; $SD = .595$). For individual participants there were changes in mindfulness and coping both after the training and six months after its completion.

Discussion and Conclusion

The aim of this article is twofold: to contribute to two of the main lines of current flourishing conceptualization and in particular to highlight the various predictors that describe levels of perceived flourishing and the practical implications of learning to flourish. Overall, our hypotheses are confirmed. Personality traits predict flourishing with low to moderate effect; personal dispositions predict flourishing with higher independent effect compared to personality traits; personality traits and dispositions have direct, mediated, and moderated effects on flourishing. Personality traits account for less variance in flourishing compared to dispositions, and traits and dispositions have both direct and indirect effects on flourishing. Among personality traits flourishing is predicted by high consciousness, agreeableness, extraversion, stability and plasticity and low neuroticism. Predictors of flourishing with independent effect among the studied dispositions are self-esteem, proactive coping, meaning in lifer and mindfulness. These findings replicate the conclusion that personality traits and dispositions are robustly related to well-being (DeNeve and Cooper, 1998; Grant et al., 2009; Sun et al., 2018; Meléndez et al., 2019; Anglim et al., 2020) and that traits and self-esteem predict flourishing (Fernández et al., 2023). To some extent, personality traits

and to a greater extent personal dispositions determine the importance of personal adaptive potential and developmental resources, which replicates that behavior is predicted by situational appraisals and coping preferences in addition to accounted for life course and other changes in personality traits that require further research (Bleidorn et al., 2022). In the general model, flourishing is predicted by high self-esteem, proactive coping, mindfulness, agreeableness, and meaning in life. Problem-oriented coping potential strengthens the relationship between agreeableness and flourishing. Conscientiousness and stability enhance the positive effect of proactive coping and mindfulness on flourishing. Plasticity strengthens the relationship between self-esteem and flourishing. This finding supports the proposed balance and joint effect of the two meta-traits, with plasticity and stability being the two dispositions specifically related to self-regulation. Self-esteem is expected to be not only stable and rigid, but also flexible enough to be revised, validated and supplemented in order to fulfill its optimal relationship with self-perception, while proactive coping and mindfulness, as dispositions related to activity in cognitive, emotional and behavioural aspect, are supported by stability. Personal dispositions and traits have their own independent effects and are also interrelated, so that each variable completes the explanatory model. Personal dispositions can support traits and personality traits have effect on dispositions and their interrelated effect contributes to the understanding of personality antecedents of self-regulation.

In terms of intervention and learning benefits, it is shown that increasing mindfulness and reducing neuroticism can improve mental health (Bleidorn et al., 2022). Intervention approaches and future perspectives for their improvement are outlined (Van Zyl and Rothmann, 2014). Effects and changes are also demonstrated for relatively stable personality traits - changes as a result of experienced crisis situations (Sutin et al., 2020, 2022) and after a three-month intervention (Stieger et al., 2019); changes in traits as a result of mindfulness facilitation (Van den Hurk et al., 2011; Stieger et al., 2019) and the influence of values (Roccas et al., 2002). In general, it is emphasized that personality traits are not "fixed," but rather plastic and change following specific experiences or interventions, as well as depending on the goals set for trait change (Anglim et al., 2020). Colaianne et al. (2025) highlight the role of learning even in a virtual environment, in supporting students' mental health and well-being. They report sustainable results with improvements in proximal outcomes related to mindfulness, compassion, and shared humanity and decreases in depressive symptoms and improvements in distal outcomes related to flourishing and depressive symptoms in the end of the course (Colaianne et al., 2025). In this study, there was partial confirmation of the expected promotion of flourishing as a result of the completed training. Participants in the training had significant changes only in the area of meaning in life, but these changes were sustainable and supportive of the learning pathways. Furthermore, meaning in life is reported to be a strong predictor of overall performance and flourishing, and individuals reported higher mindfulness and coping both after the training and six months after its completion, supporting the need for future research. Enhancing predictors of flourishing - mindfulness, coping, meaning in life, and proactive attitudes and behaviors - should act as a learned pathway to flourishing as a proximal and distal outcome.

Studies related to the COVID-19 pandemic highlight effective adaptation patterns and the role of coping potential (Kirby et al., 2021), with significant effects reported depending on the different dimensions and experiences of the crisis (Sutin et al., 2020, 2022). Since the COVID-19 pandemic, it is pointed that universities commit to supporting student mental health and well-being (Colaianne et al., 2025). For this reason, we consider the partial effect of training - sustainable results only accounted for the meaning of life important in view of the conclusion that meaning of life predicts well-being and reduces stressor-related distress (Ostafin and Proulx, 2020) and that supporting individuals' meaning-making processes promotes health (Haugan and Dezutter, 2021). The impact of a crisis situation on personal resources and coping with a difficult life situation shows that coping with a crisis situation and well-being depend on perceived challenge and meaning (Selezneva et al., 2024). Given today's unstable and insecure contexts and global crises - economic, social, threats of war, natural disasters - the need to foster resources for sustainable and effective self-regulation and the ongoing search for adaptive responses is of primary interest. We believe that the findings highlight the intersection of the integrated influence of personality predictors and proactive orientations in promoting personal efficacy, adaptive potential, self-regulation, and the role of proactive addressing, supporting the position that flourishing can be learned and that the earlier this process begins, the higher the personal effectiveness will be (Seligman, 2011).

The contribution of the study is to outline the complex framework of the interacting effects of personality predictors on experienced flourishing, and that flourishing can be facilitated through proactive,

targeted learning. Taking into account the inherent limitations of a cross-sectional study with a convenient sample, we believe that the results outline the heuristic potential of using plasticity and stability as a general research framework and practical tool that can accommodate traits, dispositions, and learning pathways. On the basis of the research results presented and the training carried out, it can be concluded that not only interventions but also the learning process can be included in order to stimulate personal adaptive resources in the perspective of positive psychology.

Conflict of interests

The author declare no conflict of interest.

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Global Research Trends of Cyberbullying and the Metaverse in the Virtual World: Bibliometric Analysis Using the Scopus Database

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Abstract: Cyberbullying has evolved from a traditional form of bullying to a more complex digital form. One of the latest aspects of this development is the emergence of the metaverse as a new arena for cyberbullying behavior. This topic has received attention in research, signaling the need for in-depth studies to understand the impact and new mechanisms of existing challenges. The research aims to identify key trends and topics in the literature on cyberbullying and the metaverse, as well as to describe the productivity of countries, institutions, authors, and publication sources. Using bibliometric analysis, the study investigates the development of research in this field over the past few years. The PRISMA method was used in the document selection process, and nine documents were found published from 2022 to 2024, including journal articles, books, and conference papers. The results of the study show that there is a significant trend and interest in cyberbullying, the metaverse, and virtual reality as the main topics. However, research linking cyberbullying to the metaverse is still limited and separate, suggesting an urgent need for research that integrates these two fields.

Keywords: *cyberbullying, metaverse, virtual reality, cybercrime, global research trends, bibliometric analysis.*

Introduction

The rapid development of information and communication technology has brought humans into an increasingly complex digital era, where social interaction is no longer limited to physical space. The virtual world has evolved from just an entertainment medium to a significant space for social interaction, especially among the younger generation. According to Kaur, G., et al., 2024, the digital world has opened up great opportunities for the emergence of new phenomena such as cyberbullying, which is defined as the use of information and communication technologies to commit repeated acts of aggression against individuals who cannot easily defend themselves. Its impact on the mental and emotional health of victims has become a global concern (Bansal et al., 2023).

Cyberbullying has been a major focus of research over the past decade, with many studies examining its psychological impact on children and adolescents. Research by Upadhyay et al. (2023) shows that cyberbullying is growing in this environment, which brings new threats to users in virtual interactions. This is supported by research conducted by Hinduja and Patchin (2010), which identifies that victims of cyberbullying are more likely to experience depression, anxiety, and decreased academic performance. Anonymity in the virtual world often exacerbates this situation, where the perpetrator feels protected from legal and social consequences (Łosiak-Pilch et al., 2022). Barlett and Gentile (2012) add that cyberbullying is often more dangerous than traditional bullying due to its rapid and widespread spread, as well as

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the difficulty of removing harmful content from the internet. The ever-evolving digital environment can exacerbate the impact of cyberbullying, especially during its peak during the COVID-19 pandemic. Marinoni et al. (2024) showed that during the COVID-19 pandemic, girls were more vulnerable to cyberbullying through social media, while boys were more vulnerable to cybervictimization in online gaming, which was affected by the time spent online.

A significant shift has occurred from traditional social media platforms to more immersive virtual worlds such as the metaverse. Technological advances have led us to the concept of the metaverse, which was first introduced by Stephenson in 1992 in his novel "Snow Crash," describing the metaverse as a virtual world where individuals can interact with each other and with a digital environment as if they were in the real world (Wijaya, 2022). The metaverse offers a more immersive and realistic virtual experience compared to conventional digital platforms (Cruz and Oliveira, 2024). However, along with this potential comes new challenges, including more complex and limitless forms of bullying in this immersive environment. The phenomenon of the disinhibition effect, in which social barriers disappear in cyberspace, also exacerbates aggressive behaviors such as bullying in the metaverse (Suler, 2004). Walther et al. (2015) mentioned that the immersive aspect of the metaverse can exacerbate the psychological impact of bullying, where negative experiences in the virtual world can feel just as real and damaging as in the physical world. Di Pomponio and Cerniglia (2024) highlighted that the use of social media and experiences in the metaverse can have a significant impact on an individual's psychological well-being, both positively and negatively, by identifying how social interactions and virtual activities affect users' mental health. Livingstone et al. (2022) argue that we are currently at a tipping point where a deep understanding of bullying in the virtual world is urgently needed to prevent damaging long-term impacts. Huang and Chou (2010) emphasized the importance of understanding this new dynamic due to the high complexity and emotional involvement in interactions in the metaverse.

A significant increase in interest in cyberbullying and the metaverse has occurred, especially since 2019. Many studies focus on the impact of online interactions on children and adolescents (Fatmawati and Haryanto, 2023). In 2022, the metaverse became a popular topic across various disciplines, but there are still few studies that explore the direct relationship between cyberbullying and the metaverse, especially in the approach to education (Cassandra et al., 2023). The metaverse, with its immersive virtual reality and anonymity, brings new risks to users, especially vulnerable groups such as children and adolescents. Therefore, it is important to study this matter. Most of the research, such as the one conducted by Kim (2021), focuses more on the commercial aspects of the metaverse compared to social issues like cyberbullying. Research by Qasem et al. (2022) highlights how communication and interaction in the metaverse can create an environment that is vulnerable to cyberbullying, especially when users vent stress in virtual spaces. The study supports the need for clear policies from metaverse platforms to prevent such behavior. However, although many studies have explored the technological and social dynamics in the metaverse, as revealed by Vandebosch and van Cleemput (2009) and Cleemput et al. (2014), the main focus is still more on technology than on the educational approach to overcoming cyberbullying. Achuthan, Nair, et al. (2023) also show that online exploitation and cyberbullying are growing on various social media platforms, but their application in the metaverse is still minimal in the literature. A study by Hendry et al. (2023) highlights prevention strategies through education and technology consulting, but does not fully target policy intervention areas in the metaverse.

Some research, such as the one conducted by Boboc and Damaševičius (2024), discusses the use of extended reality (XR) technology to address bullying but does not specifically research the metaverse. Meanwhile, Ivanov and Ramos (2020) propose the use of role-playing in virtual environments to address bullying, but its integration with the metaverse has not been fully researched. Fadhel et al. (2024) uncover the role of AI in creating immersive virtual environments in the metaverse, where social behaviors such as cyberbullying can emerge and evolve; however, the study has not yet fully identified areas that require policy intervention. Kiriakidis et al. (2019) add that understanding this new form of bullying is a crucial step in developing relevant policies and interventions in the digital era. However, the study focuses more on the technological aspect than the educational approach to addressing this problem. Additionally, global research trends show an increase in cross-cultural collaboration in cyberbullying research, with the United States leading the number of publications, followed by significant contributions from Asian countries (Peker and Yalçın, 2022; Peker and Yalçın, 2022). Currently, Ireland is the country with the highest research impact (Li and Li, 2024). These studies often highlight how the COVID-19 pandemic

exacerbated cyberbullying incidents due to increased digital dependence. Meanwhile, metaverse-related publications saw a significant surge in 2022, with Singapore, Japan, China, and the United Kingdom as the main contributors (Bizel, 2023). However, there has been no in-depth research focused on cyberbullying and metaverse research trends by exploring the interaction between cyberbullying and the metaverse. Although publications in both areas continue to increase, there are still deep shortcomings in the literature. Existing research is still limited to a few countries, and the involvement of studies in the literature has not fully met the need for a more comprehensive and in-depth analysis of the interaction between the metaverse and cyberbullying.

This study seeks to explore gaps in the existing literature by conducting a comprehensive bibliometric analysis of global research trends on cyberbullying and the metaverse, using data from the Scopus database. It aims to provide an overview of the need for further research to fill the research gap regarding cyberbullying and the metaverse, as well as its implications in education.

Research Objectives and Questions

The purpose of this research is to identify key trends and topics in the literature on cyberbullying and the metaverse, as well as to describe the productivity of countries, institutions, authors, and publication sources. This analysis reveals increasing publication trends, identifies key research themes, and highlights potential areas for future research. This research specifically seeks to answer the following questions:

Research Question 1: "What is the trend of research development on cyberbullying and the metaverse in recent years?"

Research Question 2: "Which countries and universities are making a major contribution to cyberbullying and metaverse research?"

Research Question 3: "Which authors and sources have made major contributions to cyberbullying and metaverse research?"

Research Question 4: "What is the dominant topic in cyberbullying and metaverse research?"

Materials and Methods

This research is a bibliometric study conducted to systematically identify the literature (Burgos, 2024). This research is known as text data mining, and in its development, it is often referred to as the big data method (Hassani et al., n.d.). This method adopts a five-stage approach (Tranfield et al., 2003). The research will involve bibliometric mapping using tools such as Biblioshiny to analyze global research trends (Nurhayati, 2024). Bibliometrics can uncover research trends, identify research shortcomings, and explore the relationships between studies (Ardiansyahroni et al., 2023).

Figure 1. Five-step method bibliometric analysis

Determine Search Keywords

By using bibliometric mapping and keyword analysis of indexed articles, this study aims to understand the themes as well as the research groups relevant to the topic. This approach helps researchers gain in-depth insights into the development and contribution of a field of science and measure the impact of research on the scientific community (Sumedang, 2024). The first step in this method is to collect data through the academic database "Scopus," using specific keywords, namely "cyberbullying" and "metaverse." The search process will follow clear inclusion criteria by including empirical studies that measure the relationship of cyberbullying in the context of the virtual world.

Initial Search results

From the search results on the Scopus database on July 23, 2024, 23 documents were found to have been published with these keywords. The documents identified are in the form of scientific articles, books, and conference proceedings relevant to the topic of cyberbullying and the metaverse in the context of the virtual world. The time range for the publication of the documents is from 2022 to 2024, which shows that the documents are still relatively new.

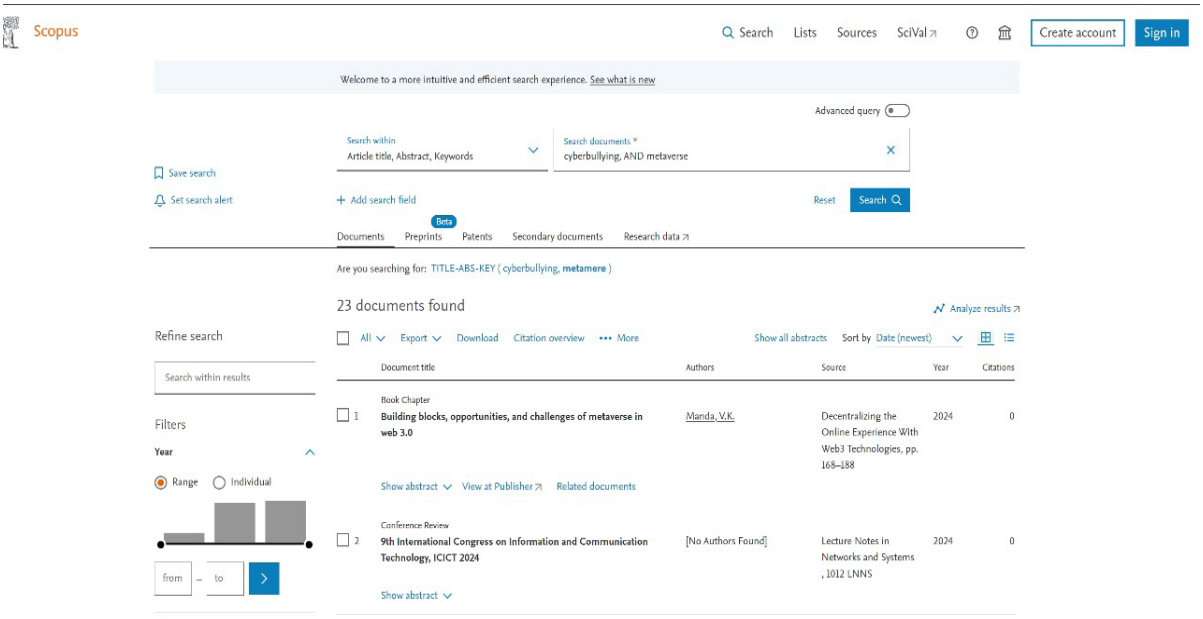

Figure 2. Meta data mining results on Scopus database

Refinement of Search Results

Documents will first be filtered by title and abstract. Irrelevant documents are eliminated at this stage, followed by a full review to ascertain whether they are relevant to the purpose of the study. In this stage, the PRISMA method is used to ensure that the document selection process is carried out in a transparent and usable manner (Liberati et al., 2009).

The prism process helps to select relevant and valid documents from the initial search results by setting filters based on the criteria of document type, keywords, and language (English). Of the 23 documents found through a search in Scopus, as many as 9 documents were selected for further analysis after going through the stages of identification, screening, and feasibility assessment. No documents were disqualified due to incomplete or irrelevant information.

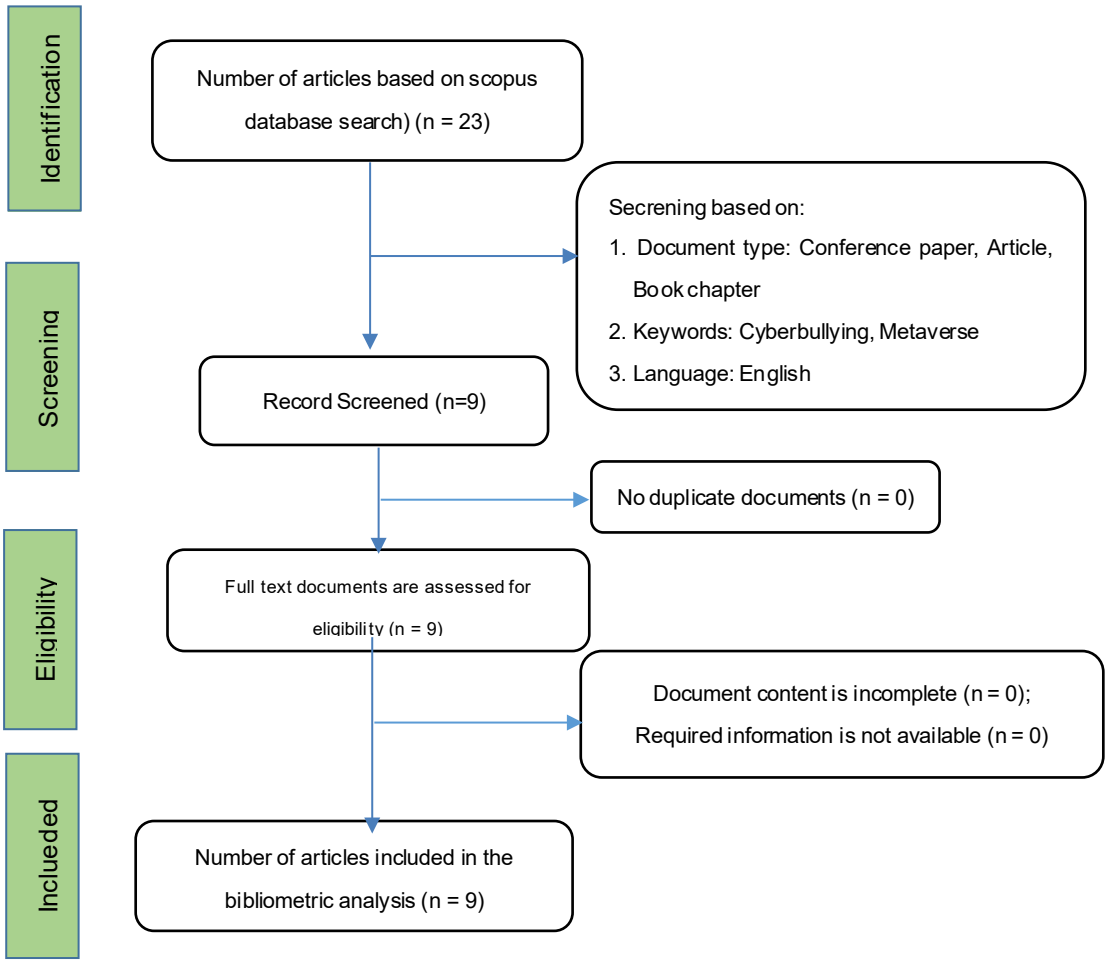

Figure 3. Stages of the PRISMA method

Compile Preliminary Data Statistics

The data collected from the 9 documents were then categorized based on several components, including the year of publication, volume, and number of citations. Each component is inspected to ensure the completeness and accuracy of the data. In addition, the source of publication and the name of the publisher of each document are also analyzed to understand the distribution and origin of the publication.

Data Analysis

Once the relevant documents have been selected, the next step is data analysis. Bibliometric analysis involves publication calculations, citation analysis, and trend identification (Santika et al., 2024). This process includes defining search keywords, conducting initial searches, filtering results, collecting statistics, and analyzing data. To answer the research question, it employs three main approaches. First, a performance analysis is carried out by calculating the number of citations and publications from research topics. Furthermore, mapping is used to describe research topics that often appear in the dataset through tree maps, as well as to track their temporal trends with plots depicting thematic evolution. Finally, network analysis is conducted through keyword co-occurrence to reveal the relationship between keywords in the same document, as well as to identify keyword clusters that form the core topic in the research field.

Results

Research Question 1: "What is the trend of research development on cyberbullying and the metaverse in recent years?"

1. General Statistical Information and Research Trends

The results of this study provide an overview of research trends and statistical information from published documents. It was found that there were nine documents published in the period from 2022 to 2024.

Table 1. Research Trends

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2022:2024
Sources (Journals, Books, etc)	9
Documents	9
Annual Growth Rate %	100
Document Average Age	0.667
Average citations per doc	2.444
DOCUMENT CONTENTS	
Keywords Plus (EN)	85
Author's Keywords (DE)	32
AUTHORS	
Authors	40
Authors of single-authored docs	0
AUTHORS COLLABORATION	
Single-authored docs	0
Co-Authors per Doc	4.44
International co-authorships %	11.11
DOCUMENT TYPES	
article	3
book chapter	1
Conference Paper	4
letter	1

This table shows that there are nine documents issued from 2022 to 2024, with an annual growth rate of 100%. This indicates a significant increase in the number of publications. These documents are still relatively new, with an average age of 0.67 years, and have earned an average of 2,444 citations per document, which reflects a good initial impact. There are 85 additional keywords and 32 author keywords, reflecting the broad scope and variety of research topics in the field being studied. All documents are the result of collaboration, involving a total of 40 authors with an average of 4.44 authors per document. The level of international collaboration reached 11.11%, indicating the existence of cross-border cooperation in this study. The types of documents published include three journal articles, one book chapter, four conference papers, and one letter. This type of document signifies substantial contributions in various academic forums, as well as rapid growth in research in the field being studied.

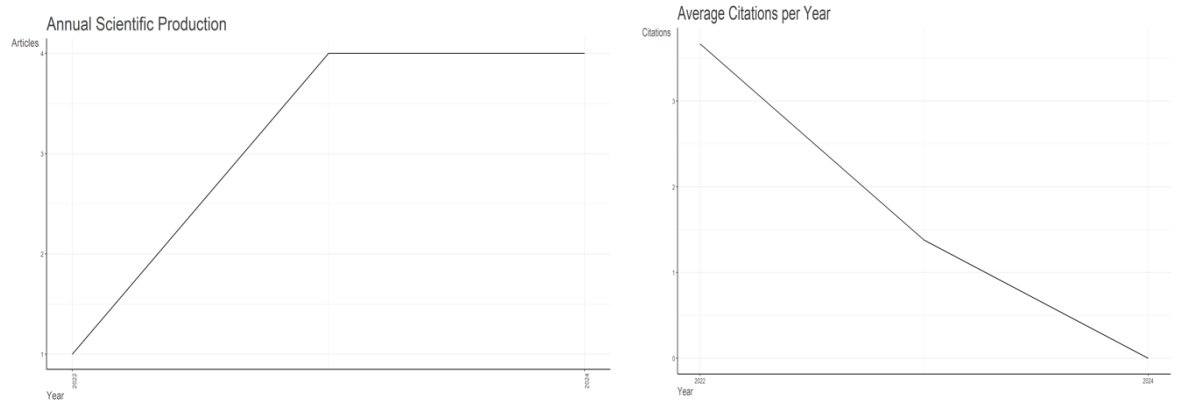

Figure 4. Annual scientific production and Average citations per year General statistical information on data (left), the trend in the number of articles (middle), and the number of citations (right)

Annual scientific production shows a significant increase in the number of articles published during this period. This increase reflects the rapid growth in research and publication activities. The trend graph shown in figure 4 (left) indicates a consistent year-on-year increase and peaks in 2024, indicating that the field of research continues to evolve and attract the attention of more researchers. The increase in the number of articles published is an indication of the surge in interest and contribution of the academic community to this topic, which is triggered by the relevance and urgency of the issue being studied.

Figure 4 (right) illustrates the increase in the number of citations, over time. This shows the relevance and influence of the published research. Publications from 2022 have gained recognition and have been referenced by other researchers, showing a greater impact than older works. It should be noted that citations tend to increase over time as more researchers access and use the work in their research.

Research Question 2: "Which countries and universities are making a major contribution to cyberbullying and metaverse research?"

2. Productivity and Impact of Countries and Institutions

The influence and contribution of publications from a country or institution can be analyzed through various bibliometric indicators. Figure 5 shows a Sankey diagram showing the relationship between the author, the keywords used, and the country from which the publication originated. This diagram makes it possible to understand how authors, research topics, and countries of origin relate to each other, as well as to provide insight into patterns of international collaboration in research.

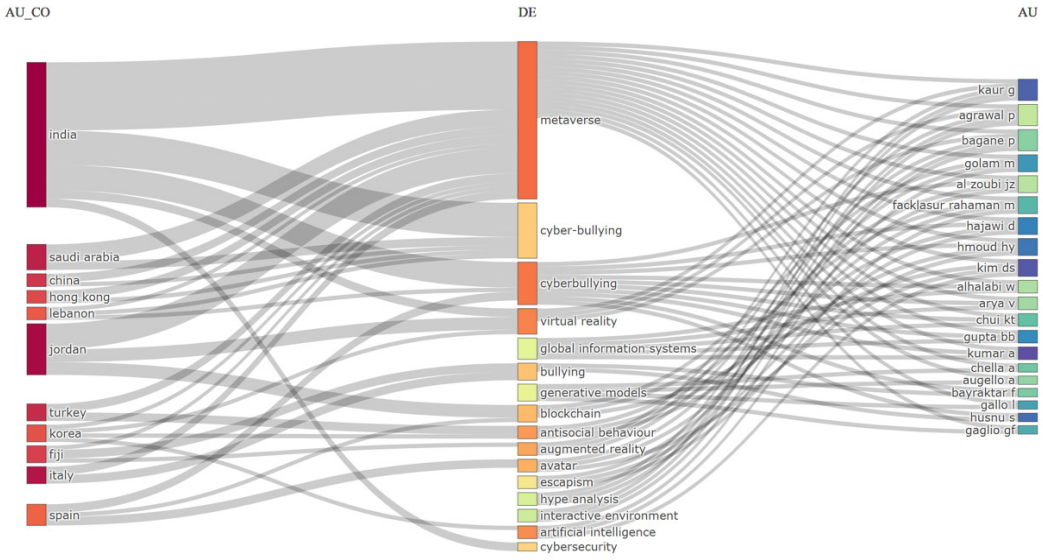

Figure 5. Three-field plot for countries of publications, keywords in abstracts, and authors

This diagram provides an overview of the relationship between leading countries and the keywords used in metaverse and cyberbullying research. The results of the analysis show that India leads in the publication of research on this topic, followed by countries such as Jordan, Saudi Arabia, Spain, Turkey, Korea, Fiji, Italy, China, Hong Kong, and Lebanon. This geographical distribution indicates a strong international collaboration in the fields of metaverse research and cyberbullying.

In the middle column, the larger red node shows the most frequently used keywords in the study, with “metaverse”, “cyber-bullying”, “cyberbullying”, “virtual reality” and “cybersecurity” as the main keywords. Other keywords that also appeared significantly included “global information systems”, “bullying”, “generative models”, “blockchain”, “antisocial behaviour”, “augmented reality”, “avatar”, “escapism”, “hype analysis”, and “interative intelligence”. These words reflect the main topics that are being explored.

On the right side of the chart, the most productive authors in this field are sorted by the number of articles published. The scatter plot shows that articles from India tend to adopt five of the sixteen main keywords namely “metaverse”, “cyber-bullying”, “cyberbullying”, “virtual reality”, and “cybersecurity”. On the other hand, articles from Jordan more often use three keywords, namely “metaverse”, “virtual reality”, and “blockchain”.

Some of the prominent authors who contributed to this study include Kaur G., Agrawal P., Bagane P., Golam M., Al Zoubi J.Z., Facklasur Rahaman M., Hajawi D., Hmoud HY., Kim D., Alhalabi W., Arya V., Chui K.T., Gupta B., Kumar A., Chella A., Augello A., Bayraktar F., Gallo L., Husnu S., and Gaglio G.F. The productivity of these authors demonstrates their active involvement in the development of research related to the metaverse and cyberbullying, which has contributed to the growth of global knowledge in this field.

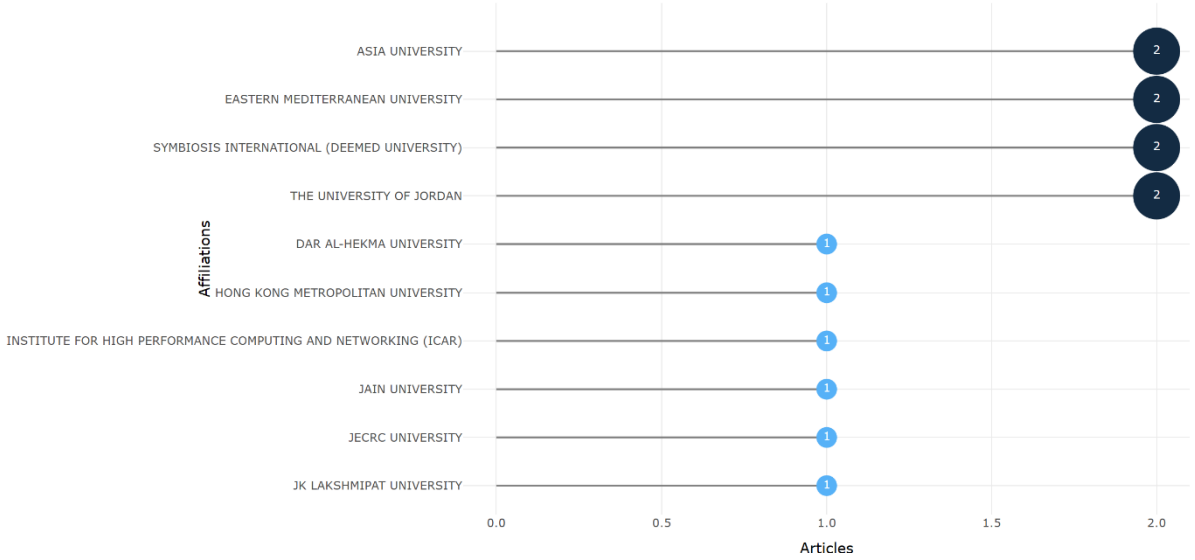

Figure 6. Top productive institutions in the world

Figure 6 highlights the ten main institutions that played a significant role in the publication of articles on the topic of cyberbullying and the metaverse during the period from 2022 to 2024. Of these institutions, four institutions each produced two articles, namely Asia University, Eastern Mediterranean University, Symbiosis International (Deemed University), and The University of Jordan. In addition, other institutional gymnastics, each published one article, including Dar Al-Hekma University, Institute for High Performance Computing and Networking (ICAR), Jain University, JECRC University, and JK Lakshmipat University. These findings show that research on cyberbullying and the metaverse has attracted attention from universities around the world, with the most notable contributions coming from institutions in Asia and the Middle East. These institutions are becoming major centers for the development of knowledge related to virtual world phenomena, demonstrating the growth of collaboration and strong interest in these topics in different parts of the world.

Research Question 3: "Which authors and sources have made major contributions to cyberbullying and metaverse research?"

3. Productivity and Impact of Sources and Authors

This section highlights authors who contributed to scientific publications. Productivity is measured based on the number of articles published by various sources as well as the number of works produced by individual or group authors.

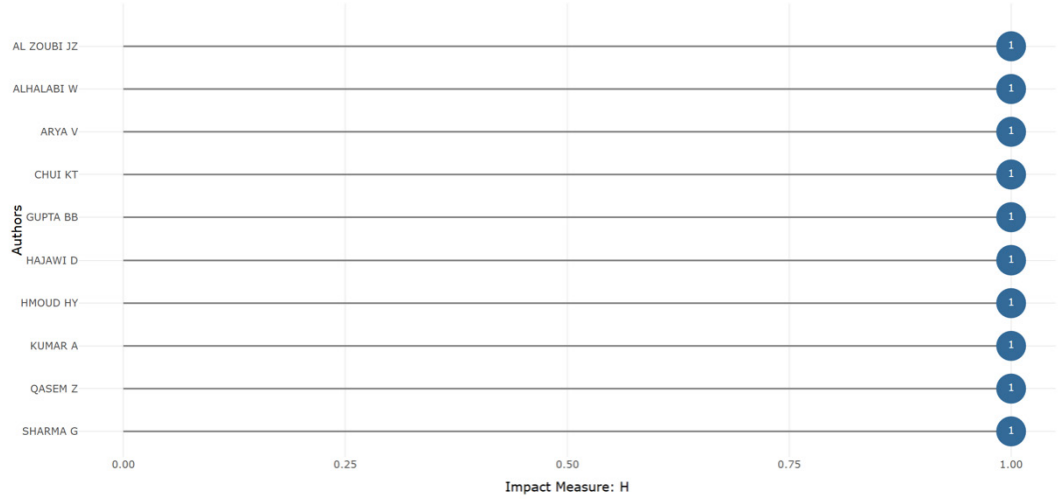

Figure 7. The connection author and publication sources

Figure 7 shows the productivity and impact of various authors, each of whom has contributed a single article to a scientific publication. The names of the authors mentioned, such as Al Zoubi JZ, Alhalabi W, Arya V, Chui KT, Gupta BB, Hajawi D, Hmoud HY, Kumar A, Qasem Z, and Sharma G, all have the same productivity figures. The impact indicator used is the h-index, which in this case is 1.00 for all authors. This indicates that each author has at least one publication that has received one citation. Although their productivity is limited (only one article), the fact that the article is cited suggests that their work has a certain impact in the academic community. To increase their influence in their fields, these writers need to increase both productivity and the number of citations in their works.

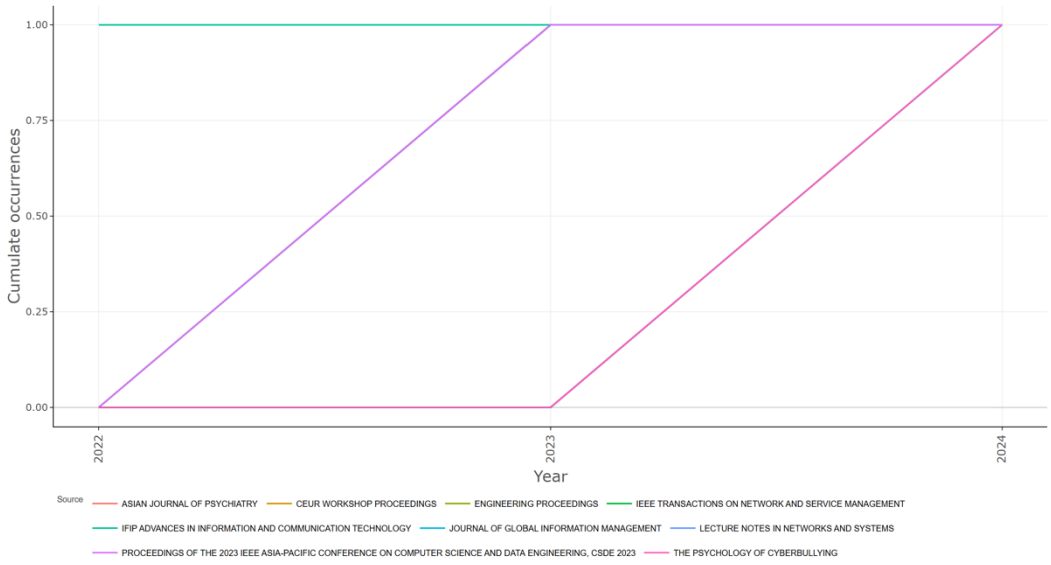

Figure 8. The connections between authors and publication sources

The cumulative connection between authors and publication sources reflects a network of scientific collaborations spread across various journals and conference proceedings. A total of nine publication

sources are the main publication sites for related research, with each publication source publishing one document from the 2022 to 2024 time span, covering a wide range of disciplines related to psychology, information technology, and network management. These sources include the Asian Journal of Psychiatry, CEUR Workshop Proceedings, Engineering Proceedings, IEEE Transactions on Network and Service Management, IFIP Advances in Information and Communication Technology, Journal of Global Information Management, Lecture Notes in Networks and Systems, Proceedings of the 2023 IEEE Asia-Pacific Conference on Computer Science and Data Engineering (CSDE 2023), and the Psychology of Cyberbullying. The connections between the authors and the various sources of this publication demonstrate the diversity of topics and multidisciplinarity occurring within the scientific community, as well as reflecting the broader impact of this research in a global context.

Research Question 4: "What is the dominant topic in cyberbullying and metaverse research?"

4. Distribution Keywords, Popular Topics, and Theme Development Trends

Keyword analysis in bibliometrics is often used in research to identify patterns and representations of specific topics that are of concern to researchers over time. The Biblioshiny program is used to analyze bibliometric data (Pathak and Singh, 2023), which helps measure how often key terms, topics, and trends come up together in various publications (Kirby, 2023).

Author keyword

Keywords plus

Title words

Figure 9. tren Author Keywords, keywords plus, and title words

The author keywords image is the result of the keyword analysis used, which describes a set of terms with large words, showing the keywords that are most often used by researchers and often appear in all research articles. The most frequently discussed keyword that became the main theme in the research article was the word "metaverse", followed by the keywords "cyberbullying", "virtual reality", and "artificial intelligence". There are also several other keywords, such as "cyber-bullying", "blockchain", "avatar", "augmented reality", "meta-governance", "mental health", "cybersecurity", "moral agents", "generative models", "non-player character", "physical reality", "bullying", "global information systems", "digital transformation", and "smart contracts". The keywords indicate areas that are closely related to this main

topic.

The keywords plus image shows the four most prominent terms: “metaverse”, “cyberbullying”, “computer crime”, and “virtual reality”. This emphasis on the plus keyword reflects an effort to explore the relationship between the use of technology and emerging social and criminal issues in digital contexts such as cyberbullying and bullying in the metaverse.

The title words image shows a text analysis that refers to the words that appear in the titles of research articles, to provide clues about the topic, focus, and main content of a document. The term can describe thematic relationships that represent latent trends in research on cyberbullying and the metaverse. Word clouds can effectively describe keywords in a study, but they are not enough to fully understand how important terms relate to each other and to the topic being researched (Rahaman et al., 2024).

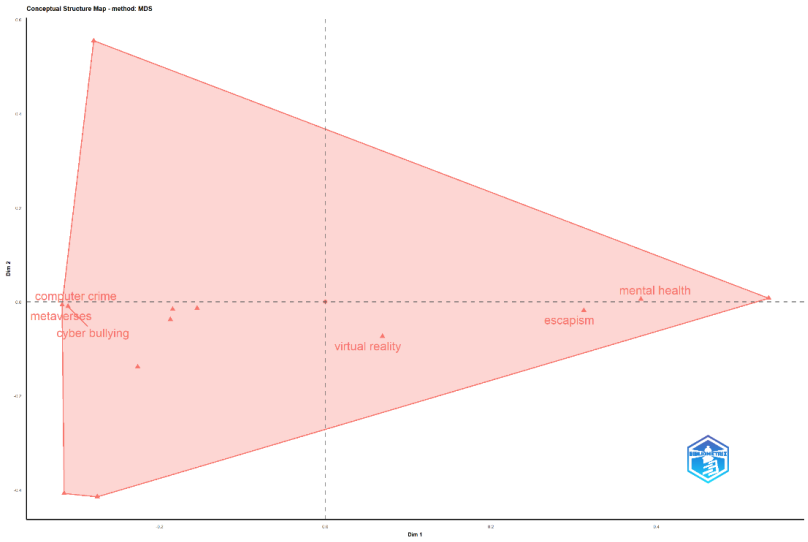

Figure 10. The conceptual structure of factor analysis

Figure 10 illustrates the conceptual structure of factor analysis that visualizes the relationship between concepts and ideas using a multidimensional approach (MDS). A variety of topics were found with the keywords “metaverse,” “cyberbullying,” “computer crime,” “virtual reality,” “mental health,” and “escapism.” In this diagram, the important terms are grouped based on their relevance in two dimensions of the analysis.

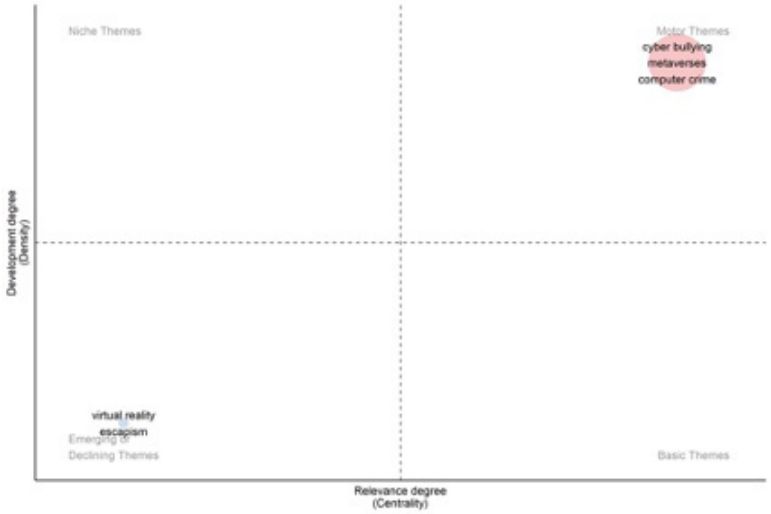

Figure 11. Thematic mapping from keywords

Figure 11 is a thematic map of the keywords in the research publication. This thematic map maps keywords based on two main axes, namely degree of relevance and degree of development. The diagram is divided into four quadrants, each of which depicts a different theme category. Quadrant 1 (top

right) contains three main themes, such as cyberbullying, metaverse, and computer crime. These themes have a high degree of centrality, which means a high level of relevance and density, indicating that these topics have developed well and become the center of attention in academic policy. Quadrant 2 (top left) represents special themes that have high density but low centrality. However, this quadrant does not show any themes. Quadrant 3 (bottom left) contains two themes that have low centrality and low density, such as "virtual reality" and "escapism." This suggests that over time, these topics declined and began to lose relevance in the study. Quadrant 4 (bottom right) contains basic themes that have high centrality but low density. In this quadrant, there are no themes. Thus, it can be concluded that the themes of "cyberbullying," "metaverse," and "computer crime" are the main and central themes in this study. Meanwhile, virtual reality and escapism are starting to decline and lose relevance in key research topics.

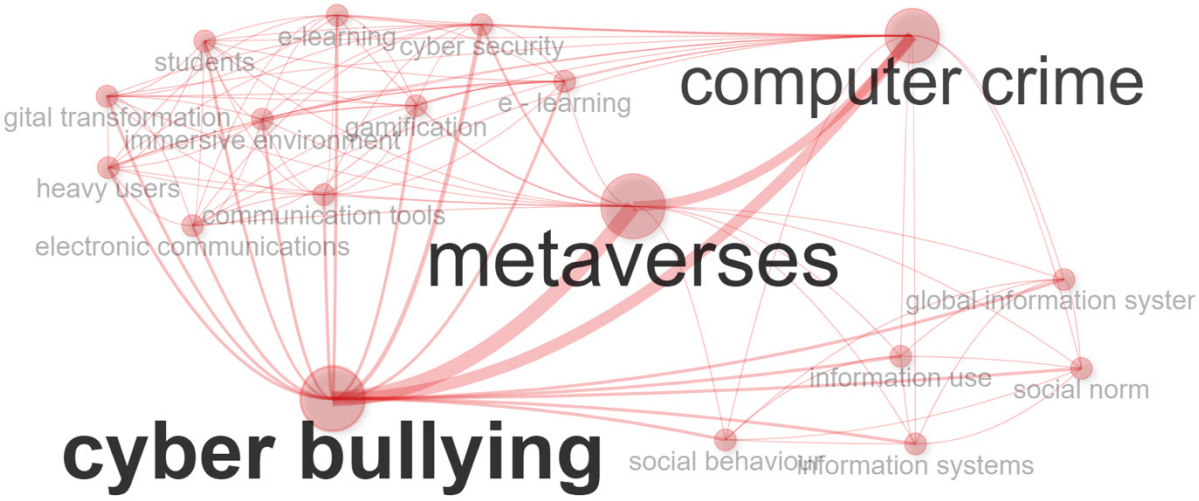

Figure 12. Co-occurence network from the topics

Figure 12 shows the network of linkages between the main topics in the study based on the concurrent occurrence of keywords in the analyzed article. The size of the circle indicates the importance of a keyword or topic, while the lines connecting the circles indicate the linkages or relationships between those topics. The large circle in Figure 12 shows that the topic of "cyberbullying" often appears in research articles. It shows that there are many connections with various other topics that are highly connected and relevant. Likewise, the topic of "metaverse" has a large circle, indicating that this topic is connected to cyberbullying, suggesting that there is a connection between the two. Computer crime is also a very relevant topic with the metaverse and cyberbullying, which shows that computer crime is often studied in the context of virtual and cybersecurity.

The lines that connect these topics illustrate connections such as "social behavior," "information systems," "information use," "social norms," and "global information systems," related to the main topic, thus showing that social behavior and information use are important factors in the discussion regarding cyberbullying, the metaverse, and computer crime. Apart from the main topic, there are several other keywords such as "e-learning," "cyber security," "gamification," "environment," "students," "communication tools," "electronic communications," "heavy users," "immersive," "digital transformation," and "students." This topic is a sub-theme in the research. The relationship between the topics of cyberbullying, the metaverse, and computer crime indicates that these three topics are interconnected and often appear together in the scientific literature.

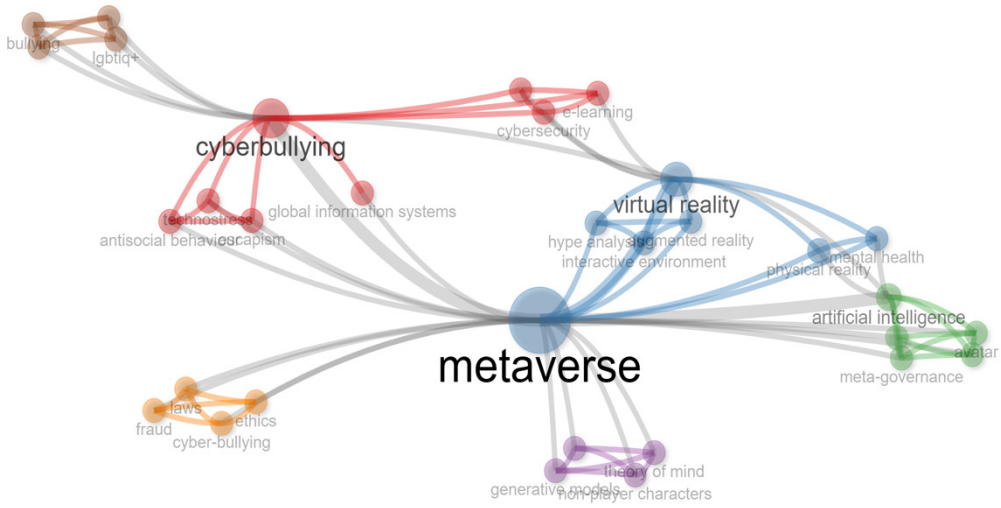

Figure 13. Co-occurence network from the topics

Figure 13 helps in identifying relevant research areas and shows how various topics are connected in the current literature. The network of associations seen in Figure 13 shows that the metaverse is a key topic that connects various research themes such as cyberbullying, virtual reality, and artificial intelligence. This relationship reflects research interest in the social, technological, and ethical implications of the growing virtual world.

Figure 14. Flow diagram of longitudinal thematic evolution

Figure 14 shows a thematic evolutionary analysis to track developments and dynamic changes in research themes focused on the metaverse and cyberbullying. Documents discussing these two themes were found from 2022 to 2024. On the left side of the image, it can be seen that in the 2022-2023 period, the most prominent and dominant keyword in the discussion in the research articles is the metaverse. Then, on the right side in the 2024-2024 period, there is a thematic shift with the emergence of additional keywords such as cyberbullying, which shows that the topic of research is starting to shift towards social problems that arise in the virtual world.

Discussions

The research aims to identify key trends and topics in the literature on cyberbullying and the metaverse, as well as describe the productivity of countries, institutions, authors, and publication sources. Related to cyberbullying and metaverse research, nine documents were found published from 2022 to 2024, with various types of documents, including three journal articles, one book chapter, four conference papers, and one letter. The diversity of these document types shows a multidisciplinary and substantial contribution in various academic forums. The research documents are still relatively new, with an average age of about 0.67 years, but have had an impact, with an average of 2,444 citations per document, showing a significant increase in the number of publications each year. This indicates that this topic is

increasingly attracting attention and showing a good initial influence in the scientific community. The nine published research papers each offer different but complementary perspectives in providing an overview of the dynamics of the virtual world and its implications for social behavior in technology.

Research on cyberbullying and the metaverse has reached a global scale, each highlighting important issues in their contexts. Rusyidi (2020) revealed that cyberbullying has become a global issue with a negative impact on victims. Meanwhile, Koohang (2023) shows that the metaverse, as an immersive virtual platform, has potential applications in various sectors. However, although both of these topics have gained significant attention, research linking cyberbullying to the use of the metaverse is still very limited. Currently, these studies tend to be separate, each focusing on impact and potential in different contexts without exploring the linkages between the two. Advances in digital technology have resulted in new forms of bullying, including cyberbullying on social media platforms (Riswanto and Marsinun, 2020). Recently, with the emergence of the metaverse as a 3D virtual space, there are new opportunities and challenges in the field of education (Indarta et al., 2022), especially in non-cognitive aspects such as social skills and self-control (Muslihati et al., 2023). Therefore, there is still an urgent need for research that integrates these two fields to understand how the use of the metaverse can affect cyberbullying behavior and its impact on social interactions in the virtual world.

The issue of cyberbullying and the metaverse has become a global topic trend, marked by international collaboration in the development of this research. Geographically, the State of India leads in terms of the number of publications, followed by Jordan, Saudi Arabia, Spain, Turkey, and other countries. This is in line with the results of bibliometric analysis (Aguspriyanti, 2023), which has highlighted emerging trends in digital public space research, with Western countries leading the way in publications. Global interest in this topic reflects the primary focus of research on the impact of technology on social behavior and safety in the virtual world. Social behavior towards cyberbullying among adolescents has been extensively researched, emphasizing the importance of parental supervision in reducing problematic social media use (Fazry and Apsari, 2021). It is characterized by keywords that often appear in research, such as “metaverse,” “cyberbullying,” “virtual reality,” and “cybersecurity.” Likewise, the contribution of institutions from Asia and the Middle East shows the diversity of topics discussed, including the disciplines of science and technology, education, network management, and psychology.

The main focus of the research based on thematic mapping reveals that the themes of cyberbullying, the metaverse, and computer crime are the primary focuses of the research, while virtual reality and escapism tend to decrease in relevance. The following is an explanation related to the research article document discussed:

1. Research (Kaur, G., et al., 2024) “A Comprehensive Review of Metaverse: Taxonomy, Impact, and the Hype around It” reveals that the metaverse is not only a trend, but also has the potential to change social interactions, including increasing the risk of cyberbullying. The study provides a theoretical foundation about the metaverse by developing a taxonomy and exploring its impact in general.
2. Research (Upadhyay et al., 2023) “cyberbullying in the metaverse: A prescriptive perception on global information systems for user protection” shows the urgency of developing a virtual world user protection mechanism to deal with cybercrime, including cyberbullying in the metaverse.
3. Research (Grover et al., 2023) “Social Commerce and Metaverse in a New Virtual World: Exploring Women’s Adoption Intentions” Her study contributes to revealing the potential of the metaverse as a social and economic platform, but is vulnerable to the threat of cyberbullying, especially among women.
4. Research (Pathak-Shelat and Mehta, 2023) “The Future of Higher Education in Ethical Metaverse: Co-existing in Virtually Enhanced Physical Reality” discusses the role of institutions in combating cyberbullying behavior in an ethical metaverse through an ethical-based approach, by introducing an education system that is its bulwark.
5. Research (Yildiz, I. and Tanyildizi, N.I., 2022) “An analysis on news containing cyberbullying in the metaverse” shows that the public perception of the risks of cyberbullying in the metaverse is beginning to develop. The analysis is based on the representation of cyberbullying in the metaverse through media coverage, so it can help validate the importance of raising awareness of the dangers lurking in the virtual world.
6. Research (Qasem et al., 2022) “The effect of technostress on cyberbullying in metaverse social

platforms" investigates the relationship between technostress and cyberbullying, the results of which can strengthen the understanding of behaviors that can trigger cyberbullying in the digital environment. This research is very relevant because it links stress due to technology with an increased risk of negative behavior on metaverse social platforms.

7. Research (Sanchez-Romeo, C. and Munoz-Jimenez, E.M., 2024) "Immersive environments at school: stop cyberbullying by proximity" offers virtual proximity-based solutions used to combat cyberbullying. This study is relevant in the context of Education to mitigate cyberbullying behavior among students. It emphasizes that the same technology that can be used to harm, can also be used to protect.
8. The research (Rahaman et al., 2024) "Meta-Governance: blockchain-driven metaverse platform for mitigating misbehavior using smart contracts and AI" introduces the potential of innovative technologies to address bad behavior in the metaverse using blockchain and smart contracts. Not only monitoring but also automatically controlling negative behavior on the metaverse platform.
9. Research (Bayraktar, F. and Husnu, S., 2024), "Risk and protective factors in LGBTIQ+ Cybervictimization" This study shows that vulnerable communities become victims of negative behavior, such as the LGBTIQ+ community in the metaverse, so they need special protection in a virtual environment.

Each study offers a different but complementary perspective. The study conducted by Kaur et al. (2024) provides a holistic view of metaverse trends, while more focused research, such as that conducted by Upadhyay et al. (2023) and Yildiz and Tanyildizi (2022), explores user protection against the risks of cyberbullying and bullying in the metaverse. At the same time, Grover et al. (2022) conducted a study on the adoption of the metaverse in the context of social commerce. This is reinforced by research from Bayraktar and Husnu (2024), which reveals that the threat of cyberbullying is particularly vulnerable to the LGBTIQ+ community, indicating that a comprehensive approach is needed in the virtual world. Several innovative solutions have been proposed by researchers, such as those proposed by Rahaman et al., 2024Facklasur et al. (2024) with the use of blockchain and AI, as well as by Pathak-Shelat and Mehta (2023) through the application of ethical approaches. Both studies provide solutions to protect against negative behavior in the virtual world through the involvement of technology.

Future research is expected to increase international collaboration and exploration of relevant topics. The metaverse is predicted to make a significant contribution to global GDP growth, with applications in education, health, business, and entertainment (Syahrul and Baidarus, 2023). In education, the metaverse offers an interactive online learning experience, overcoming limitations such as classroom capacity and distance constraints (Setiawan, 2022). However, the emergence of digital technology also raises concerns about cyberbullying, which can have psychological and physical impacts on victims (Fathoni and Prasodjo, 2022). Research on cyberbullying and the metaverse is still limited, and there are many other aspects that have not been developed, such as the exploration of its impact on antisocial behavior, policy interventions in the educational environment, and the transformation of cyberbullying into bullying in the metaverse.

Conclusions

The topic of cyberbullying and the metaverse has become a significant global concern. The findings show that India made a major contribution to the publication of the study, followed by Jordan, Saudi Arabia, Turkey, Korea, Fiji, Italy, China, Hong Kong, and Lebanon. Various universities in these countries are leading in the production of research in this field. Key authors and leading journals also play an important role in the dissemination of related research. The analysis shows an increase in publications related to these two topics, with the discovery of nine still relatively recent documents published between 2022 and 2024. These documents, such as journal articles, books, and conference papers, deal extensively with the impact of technology on social behavior in the virtual world. Themes such as cyberbullying, the metaverse, virtual reality, and cybersecurity dominate the literature. However, research linking these two topics is still limited and separate. Therefore, it is important to recognize the urgent need for research that integrates these two fields. The metaverse brings new challenges, especially when it comes to cyberbullying and its impact on social interactions. Future research should expand this study by exploring the transformation of cyberbullying into bullying in the metaverse environment, as well as developing effective policy interventions in the field of education to address this problem.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, H.A. and A.M.; methodology, A.M. and H.H.; software, H.A., A.M. & H.H; statis- tical analysis and interpretation, and writing; E.P. and M.N.W.; supervision and critical revision, and editing.

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A Web Application for Learning Support Vector Machine Algorithms in Computer Engineering

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Abstract: In this paper, we present a web application designed for learning and visualizing Support Vector Machine (SVM) algorithms, which are key components in the fields of machine learning and data processing. The application was developed as an interactive tool that allows students and researchers to experiment with SVM models, providing insight into their structure and functionality. By using modern web technologies, the application offers a user environment that is accessible, intuitive, and adaptable for learning and research. In addition to implementing a web tool for learning the SVM algorithm, this study proposes a method for its application in teaching and analyzes the impact of applying the new interactive method on final learning outcomes. To assess the effectiveness of this tool, an experiment was conducted consisting of three phases: pre-testing, training, and post-testing. To evaluate students' experiences with the applied alternative learning method using the auxiliary tool and their perception of the software system's effectiveness, the standardized System Usability Scale (SUS) was used.

Keywords: *Support Vector Machine, educational technology, algorithm visualization, simulation systems, educational tools.*

Introduction

With the development of machine learning, intelligent software systems are increasingly being developed today, which, based on input data, use one or a group of algorithms to provide appropriate output data as a result of execution. Machine learning algorithms are used in a wide range of different fields, including medical diagnostics, control of robotic systems, management of industrial systems, telecommunications, finance and stock trading, the computer game industry, the music industry, and many others. However, in many cases, machine learning models are considered black boxes because the inner functionality of the underlying algorithms is not entirely understandable to analysts (Mühlbacher et al., 2014), and even for experts, tuning and parameterizing certain models can be challenging (Zeiler and Fergus, 2014). Due to the complexity of machine learning algorithms, there is a need for systems that enable their application in everyday work as well as in the education process. Well-known software systems, environments, and libraries for research and concrete application of machine learning algorithms are Weka (Hall et al., 2009), TensorFlow (Abadi et al., 2015), PyTorch (Paszke et al., 2019), Scikit-learn (Pedregosa et al., 2011), Keras (Chollet et al., 2015), and Shogun (Sonnenburg et al., 2010). The focus of this paper is on systems used as support in education to help students understand the dynamic behaviors of machine learning algorithms. The analysis of existing educational tools for visualization and simulation of machine learning was conducted in the second section.

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The goal of machine learning is to construct algorithms capable of learning to predict specific target outputs. To achieve this, the learning algorithm is given specific training examples that demonstrate the target relationship between input and output values. The algorithm should generate approximately correct output, including examples that it did not encounter during training. For a good understanding of these topics, undergraduate students need to master other areas of computer engineering, and it is desirable to have some prior knowledge, which is often not acquired at previous levels of education (Çağlayan, 2019). Therefore, it is very important to properly motivate students to learn these topics. Some of the pedagogical methods recommended for teaching machine learning are hands-on tasks, collaborative learning, and problem-based learning (Hazzan and Mike, 2023). Hands-on tasks involve engaging students in real hands-on projects that include data collection, model training, and performance evaluation. This encourages practical application and solving the set tasks. Through the analysis of real problems, Problem-Based Learning helps students develop critical thinking and practical problem-solving skills. Collaborative learning allows students to solve problems together, share ideas and learn from each other. Computer engineering continuously strives for innovations in pedagogical methods and tools, especially in the field of machine learning. Auxiliary software tools should enable students and future engineers to visualize and simulate different algorithms for educational purposes and to gain insight into the possible effects of certain algorithms, thus more easily selecting the appropriate algorithm for specific needs and optimally determining the parameters with which to use the appropriate algorithms through simulation.

Rutten et al. (2012) considered a large number of experimental studies on the effects of software tools in teaching published over a decade. Many studies reviewed in that work compare working conditions with and without auxiliary tools, showing positive results in favor of using software tools to improve traditional learning methods. Today, it is common to use different learning support tools in computer engineering courses during laboratory exercises. In courses more oriented towards studying hardware and abstract systems, such tools are often software simulators (Djordjevic et al., 2005; Jovanovic et al., 2012; Stamenkovic and Jovanovic, 2024) whose task is to simulate the system being studied. In software courses, tools for visual representation of algorithms are often used (Thakur et al., 2011; Stamenkovic et al., 2023). The field of designing tools for the visual representation of algorithms has a long tradition, and many such software systems have been realized so far. Interpreting machine learning models is currently a popular topic in the information visualization community, and the results demonstrate that insights from machine learning models can lead to better predictions and improved reliability of results (Chatzimparmpas et al., 2020). With the growing popularity of machine learning, there is also a greater need for systems for the visual representation of algorithms in this field.

Support Vector Machine (SVM) is one of the fundamental algorithms in the field of machine learning, and understanding it is crucial for a deep comprehension of the theoretical and practical aspects of this field. Support Vector Machines (SVM) are powerful machine learning algorithms used for classification, regression, and anomaly detection (Cortes and Vapnik, 1995; Bennett and Campbell, 2000; Schölkopf and Smola, 2002). The idea of the method is to find a separating hyperplane in the vector space where the data are represented so that all data from the same class are on the same side of the plane, as shown in Figure 1. SVM finds the optimal separating hyperplane, which is the plane with the maximum margin. The margin represents the width of the separation between classes that should be maximized. SVM algorithms are characterized by their ability to effectively work in high-dimensional spaces and with data that are not linearly separable due to the use of kernel functions. Since SVM effectively classifies multidimensional data of various types, it is successfully applied in various fields, including biosciences for analyzing biological processes, medicine for analyzing medical images, DNA analysis, and predicting population structure. It is also widely used for classifying hate speech on social networks. Due to their wide application and significance, SVM algorithms are an integral part of university course literature on machine learning.

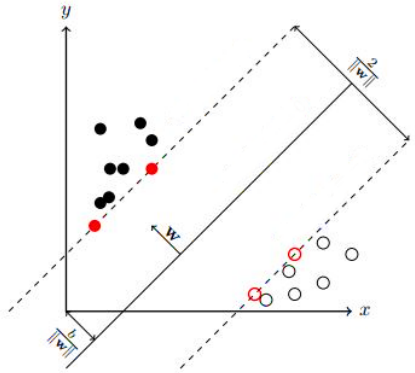

Figure 1. An example showing the optimal hyperplane with the maximum margin that separates data into two classes

The aim of this study is the development of a web application that serves as an educational tool for learning and visualizing the principles and applications of SVM algorithms. The application is developed using modern web technologies such as HTML-CSS, JavaScript, and Java EE technologies, enabling interactive and visual learning. The use of these technologies contributes to the flexibility and accessibility of the application, making it available to a wide range of users, including students and researchers.

The paper is systematized into seven sections. Following the introduction, the second section analyzes relevant literature to present existing solutions in this field. The third section describes the system architecture with an emphasis on modular design, integration with databases, and how SVM processing is performed within the application. A detailed description of the user interface, with examples of how users interact with the application, including the visualization of SVM models, is presented in the fourth section. The fifth section presents a case study that precisely describes the strategy for learning the SVM algorithm using the developed auxiliary tool. The sixth section provides a detailed description of the conducted experiment and the results of the tool evaluation, along with a discussion. Conclusions and suggestions for future work are presented in the seventh chapter.

Literature Review

Learning support tools are part of the modern educational process. The main task of these systems is to enable users to master the material more easily. Nowadays, there are a large number of diverse learning support systems. Depending on the field of application and the level of knowledge required to use the system, the technology applied for system implementation and the didactic methods that the systems implement differ. For supporting the learning of algorithms in the fields of machine learning and artificial intelligence, visualization and simulation tools for algorithm operation are successfully used. The perception of reality is fundamentally visual, and in many cases, humans use symbolic processing, visual diagrams, and other forms of imaginative processes to gain intuition about what, in its formal aspect, has an abstract structure (Díaz, Dormido, and Rivera, 2015). Today, it is widely accepted that visualizing information about the internal workings of complex algorithms can contribute to better understanding and offer solutions for better and more interpretable machine learning models (Sacha et al., 2017). Below, some of the systems developed as tools to support learning algorithms in the fields of machine learning and artificial intelligence will be presented.

Principal Component Analysis (PCA) is the most commonly used procedure in exploratory data analysis and in machine learning for predictive models. However, due to its complexity, the mechanisms and results of this operation are difficult for users to understand. To help students better understand and use PCA, Jeong et al. (2009) developed a system called iPCA (interactive PCA), which visualizes the results of principal component analysis using multiple different views and a rich set of user interactions. The interactive iPCA system with an example is shown in Figure 2. As can be seen, the visualization is realized at a high level through multiple different views, and there are options for configuring the parameters of the operation.

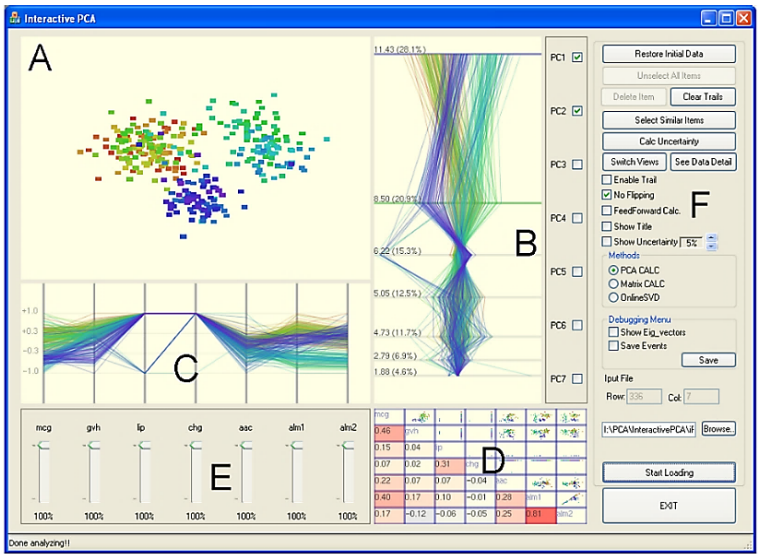

Figure 2. Interactive iPCA System: (A) Projection View; (B) Characteristic Vectors Overview; (C) Data View; (D) Correlation Overview; (E) Dimension Control; (F) Adjustment Options.

Mayfield and Rosé (2010) focus on the development of an interactive tool that aids in the analysis of errors in the text retrieval process. The proposed tool is designed to enable users, especially students and researchers, to more easily identify and understand errors that occur during text classification. The paper emphasizes the importance of understanding errors in machine learning models and presents a user interface (Figure 3) that allows for visual exploration and analysis of errors. The proposed tool is useful for education because it provides deeper insight into the decision-making processes of machine learning models.

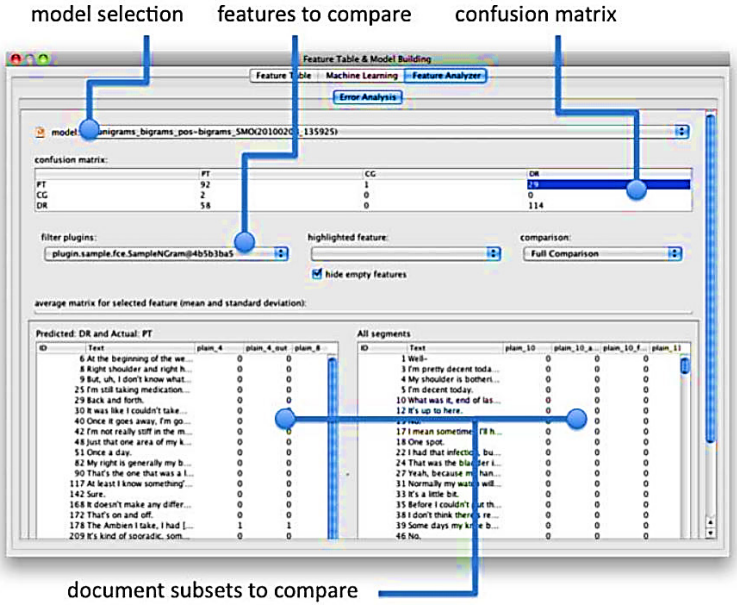

Figure 3. Interface of the error analysis tool in the text retrieval process

Kim et al. (2021) presented an interactive framework for demonstrating symbolic regression that allows users not only to perform general configuration but also to control the system during training. The demonstration system for symbolic regression enables user interaction with the DSR (deep symbolic regression) algorithm. The interface provides real-time visualization and diagnostics to help the user monitor and control the algorithm. The interactive platform includes visualization of top-performing mathematical expressions and real-time algorithm diagnostics. This software system consists of a core algorithm (DSR) running in the background, a framework for algorithm visualization, and an adaptive user interface for data

loading and real-time configuration (Figure 4). The interactive platform is web-based, meaning that the user interacts with the algorithm through a web browser while execution is performed on the server side.

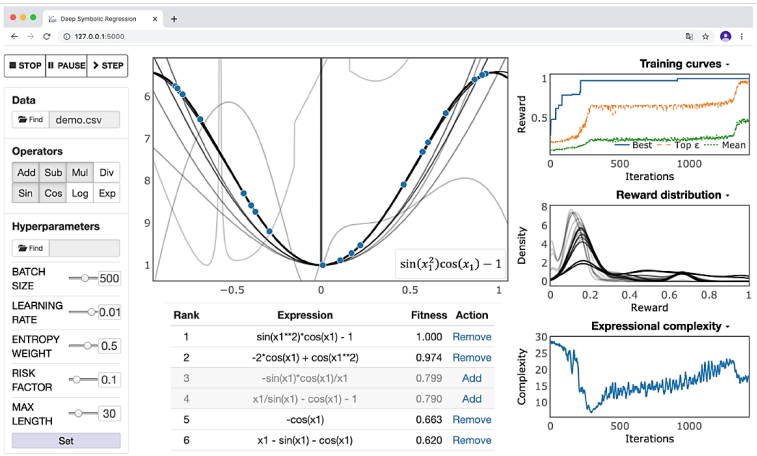

Figure 4. User interface of the symbolic regression demonstration tool

NNeduca (Jovanovic et al., 2023) is a software environment designed for teaching and learning the principles of artificial neural networks. The tool was created with the intention of improving both teaching methods and learning outcomes. The proposed system can be used to design a neural network with any number of layers and an arbitrary number of neurons in each of those layers. The development process of the neural network is flexible and configurable, the technical features and appearance of the environment are customizable, and the choice of transfer function for each layer is optional. All processes in neural networks are presented visually, and the results are illustrated using appropriate graphs. Neural networks can be applied to both regression and classification tasks, making this tool applicable for various calculations in many fields. The system focuses on students for whom studying neural networks is a challenging task, providing them with the opportunity to experiment with different types of neural networks, adjust parameters, train networks on various datasets, and visually analyze the results through an intuitive user interface.

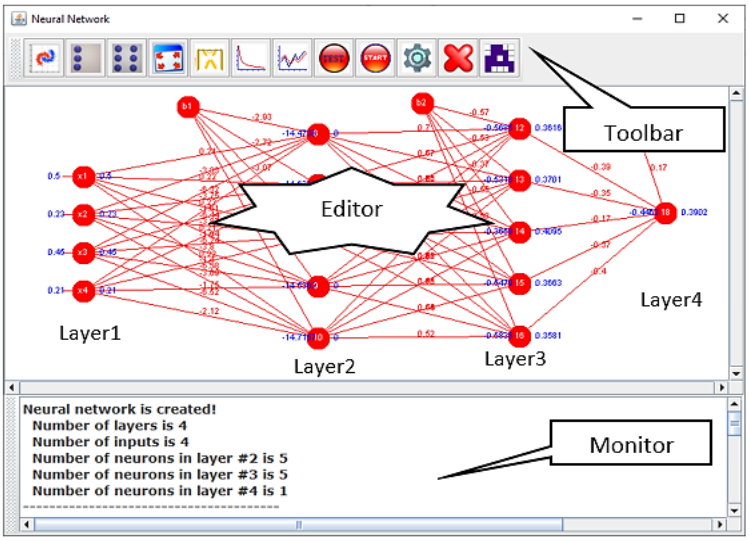

Figure 5. User interface of the NNeduca software environment

No tool developed at any university for assisting in the learning of SVM algorithms was found in the literature search. This fact served as an additional motivation for the development of such a system.

System architecture

Figure 6 shows the architecture of the software system. The basic components of the system are:

1. Frontend (HTML, CSS, JavaScript):
   - HTML, CSS, JavaScript: The user interface allows the input of parameters for the SVM model.
   - AJAX: Enables asynchronous data sending and receiving of results without refreshing the page.
   - Visualization System.
2. Backend:
   - Java EE**:** Enterprise application for handling user requests and business logic.
   - SvmServlet: Receives AJAX requests with parameters, forwards them to SvmProcessorBean, and returns results as JSON.
   - SvmProcessorBean: Processes data, trains the SVM model using libsvm, and returns results to the servlet.
3. Libraries:
   - libsvm: Library for implementing SVM algorithms for model training.
   - D3.js: Visualizes results through interactive graphs.

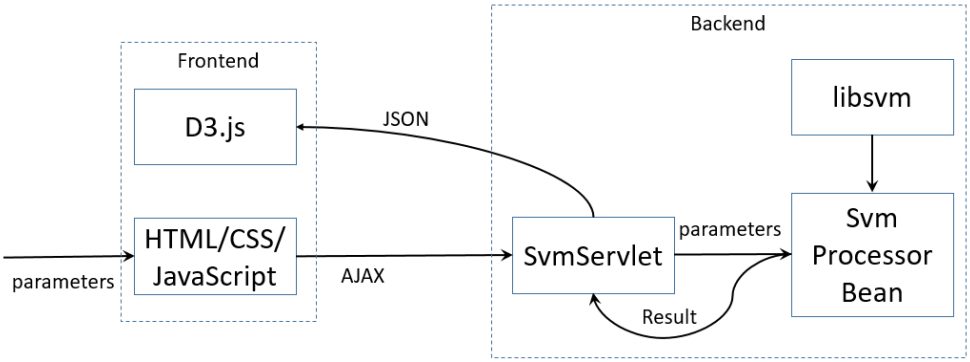

Figure 6. System architecture

The user configures parameters for the SVM model via the web interface (frontend) by entering values such as the type of SVM, kernel function, C, gamma, and other parameters. Once the parameters are set, an asynchronous HTTP request is sent to the SvmServlet (backend) using AJAX, which provides a smooth user experience without requiring page reloading. The SvmServlet receives these parameters and forwards them to the SvmProcessorBean component. The SvmProcessorBean uses the libsvm library to train the SVM model with the given parameters. After processing, the SvmProcessorBean returns the results to the SvmServlet, which then sends a JSON response with the results back to the frontend via AJAX. The results are then displayed on the frontend using D3.js to create interactive graphs, which allow the user to visualize the performance of the trained model.

This architecture allows users to interactively experiment with SVM models using the flexibility of AJAX requests for quick processing and result visualization. All layers of the system are clearly defined and interconnected, allowing for efficient and clear handling of user requests and result visualization.

Practical work with the system

The page at https://ml.pr.ac.rs/svm.html provides an interactive environment for working with Support Vector Machine (SVM) models (Figure 7). It allows users to experiment with different types of SVMs (C-SVC, nu-SVC, one-class SVM, epsilon-SVR, nu-SVR) and kernel functions (Linear, Polynomial, Radial Basis Function, Sigmoid).

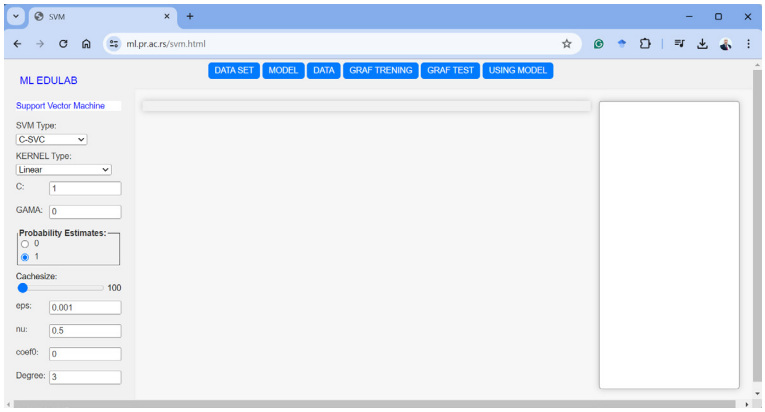

Figure 7. The main window of the application

Users can configure parameters for the SVM model via the web interface. The data are then loaded into the DATA SET module. The data is in Excel format. It is necessary to specify which columns in the Excel table represent the input data (in this case, 0,1), while the remaining columns represent the output data. In addition, the percentage of data to be used for testing must be specified (in this case, 10%). After that, by clicking the LOAD DATA button, the data will be loaded (Figure 8).

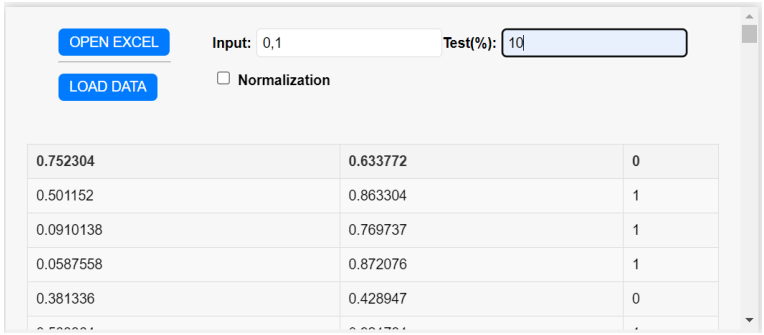

Figure 8. Data set module

The data and parameters are then sent asynchronously via an HTTP request to the backend (SvmServlet) using AJAX. On the backend, the request is processed. SvmServlet receives the parameters and forwards them to SvmProcessorBean.

SvmProcessorBean is an Enterprise JavaBean (EJB) component used to implement business logic in the SVM visualization application. Its main functions include processing parameters, training the SVM model, and generating results. SvmProcessorBean returns the results to SvmServlet.

SvmServlet is a Java Servlet component that plays a key role in the communication between the frontend and the backend of the application. Its main functions include receiving parameters, forwarding parameters, processing results, and sending the response back to the frontend. SvmServlet sends a JSON response with the results back to the frontend via AJAX. The results are displayed on the frontend using D3.js to create interactive graphs (Figure 9).

Different types of SVMs allow the algorithm to be applied to a wide range of tasks, from classification to regression and anomaly detection, providing flexibility and efficiency in solving various machine learning problems.

The user selects one of several types of SVMs. C-SVC (C-Support Vector Classification) is a classic SVM for classification. It uses regularization with the parameter C, which controls the balance between maximizing the margin and minimizing classification errors. An alternative is nu-SVC (nu-Support Vector Classification) with the parameter v (nu), which controls the upper bound on the fraction of errors and support vectors, providing a more flexible approach to controlling model complexity. A one-class SVM is used for anomaly detection. Training is performed only on positive examples, and the model identifies whether new data belongs to the same class. Epsilon-SVR (Epsilon-Support Vector Regression) is a regression SVM for predicting continuous values. The parameter epsilon controls the width of the region around the

function within which errors are not penalized. Nu-SVR (nu-Support Vector Regression) is a regression SVM with parameters v (nu) and epsilon for better control over the number of support vectors and error tolerance.

Kernel functions are mathematical functions that transform data into a higher dimension so that the SVM algorithm can more easily find a separating hyperplane for classification or regression. They enable the SVM to model nonlinear boundaries between classes. In the application, the following kernel functions can be used:

1. **Linear**: Uses a linear kernel, the simplest function for separating data. It is efficient for high-dimensional data.
2. **Polynomial**: Uses a polynomial kernel that can model nonlinear relationships. Parameters include the degree of the polynomial and the coefficient.
3. **Radial Basis Function (RBF)**: The most commonly used kernel for SVM. The parameter gamma controls the width of the RBF and adjusts the flexibility of the model.
4. **Sigmoid**: Uses a sigmoid kernel, which is similar to the neuron activation function. It can model nonlinear relationships and is used in support vector networks.

Within the SVM (Support Vector Machine) model, there are several parameters that can be adjusted to optimize performance. Understanding these parameters is crucial for effectively using SVM algorithms in machine learning. Below is a detailed description of the most important adjustable parameters for SVM models, explaining their function and impact on the model:

1. **C (Regularization Parameter)**: Controls the trade-off between achieving a low training error and a low testing error, which is achieved by maximizing the margin.
2. **Gamma (Parameter for RBF, Polynomial, and Sigmoid Kernels)**: Controls the width of the Gaussian curve in the RBF kernel. Lower gamma values create wider curves (smoother boundaries), while higher values create narrower curves (more precise boundaries).
3. **Cachesize**: Determines the amount of memory allocated for caching the kernel matrix. Larger values can speed up the computation of the kernel matrix but require more memory.
4. **Epsilon (Parameter for Epsilon-SVR)**: Controls the width of the epsilon-tube within which errors are not penalized. Larger values of epsilon make the model more tolerant of errors within the epsilon-tube.
5. **Nu (Parameter for nu-SVC and nu-SVR)**: Controls the upper bound on the fraction of errors and support vectors. It allows direct control of model complexity and error tolerance.
6. **Coef0 (Parameter for Polynomial and Sigmoid Kernels)**: A constant added in the polynomial and sigmoid kernels. It affects the shape and complexity of the model when using nonlinear kernel functions.
7. **Degree (Degree of Polynomial for Polynomial Kernel)**: Determines the degree of the polynomial in the polynomial kernel. Higher values make the model more complex and allow it to capture nonlinear patterns in the data.

Users can adjust these parameters to optimize the performance of their SVM models for specific problems. By experimenting with different values of these parameters, it is possible to achieve a balance between model accuracy and its generalization (Figure 9).

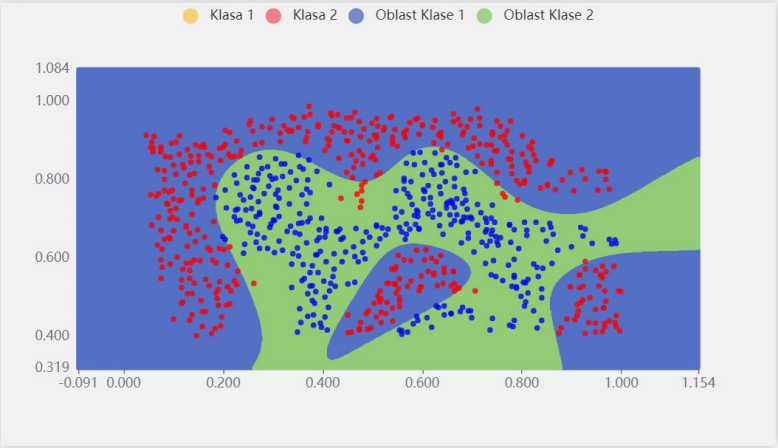

Figure 9. SVM model results visualization

The obtained model can be used for classification by clicking the USING MODEL button (Figure 10).

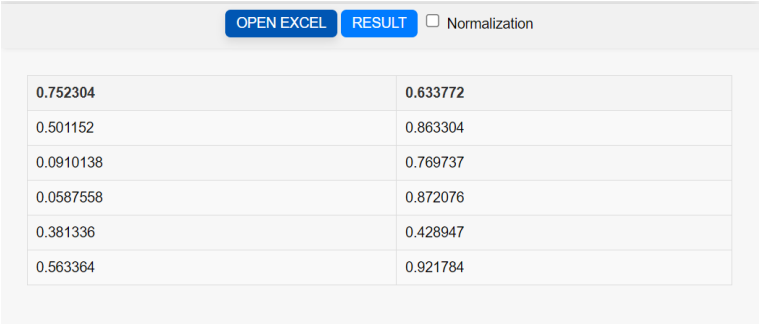

Figure 10. Test data

The data should be in Excel format, and the classification results should be obtained in graphical form (Figure 11).

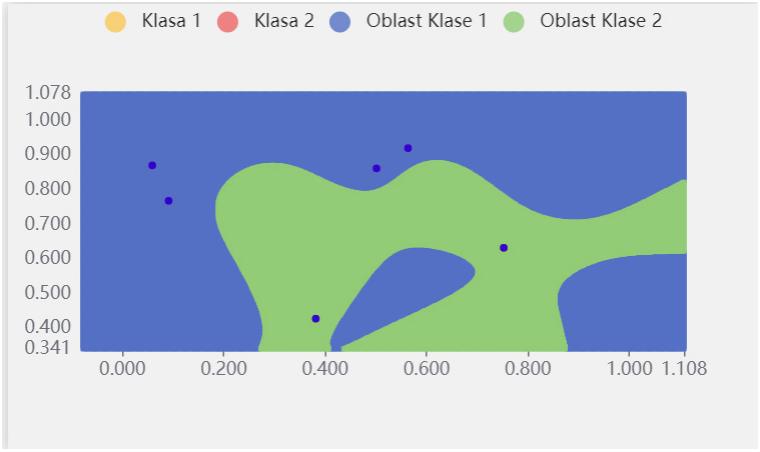

Figure 11. Classification results

This application significantly contributes to education through its interactive and practical approach. By providing users with the ability to directly experiment with different SVM models and parameters, the application enables a deeper understanding and efficient application of theoretical knowledge in practice. With its rich visualizations and flexibility, the application is an invaluable tool for students, researchers, and professionals in the field of machine learning.

Case study

The presented web-based tool is suitable for supporting the learning/teaching of SVM algorithms in all undergraduate courses that cover machine learning algorithms. The alignment of this software system with the literature used in theoretical teaching is of exceptional importance due to its usability and easier integration within laboratory exercises. Given that the tool covers different types of SVMs as well as all kernel functions, it will be suitable for many undergraduate curricula. For learning complex theoretical constructs, the active learning method is recommended (Silva et al., 2019; Pradono et al., 2013), and this method is also applied when learning SVM through the auxiliary tool. Collaboration among students also has a significant impact on learning outcomes (Guo et al., 2020). The learning outcomes of applying the realized educational tool include: (1) understanding how the SVM algorithm works; (2) identifying its advantages and disadvantages compared to other classification algorithms; (3) the ability to recognize problems for which the SVM algorithm is most suitable; (4) acquiring the skill to correctly select the appropriate type of SVM, kernel function, and properly configure it for the most efficient solution to the given problem.

For learning this algorithm, 4 hours of theoretical and 4 hours of practical instruction are recommended. The teaching should be based on the traditional paradigm of theory-examples-exercises. Thus, the strategy for learning the SVM algorithm by applying the developed auxiliary tool is as follows:

- Theoretical concepts are first presented for each topic during the theoretical lectures. (Auxiliary tools for visualization and simulation are powerful teaching aids only when used in conjunction with traditional teaching (Taher and Khan, 2014).
- Laboratory exercises involve a more detailed explanation of the topics covered in lectures using tools to visually represent the presented concepts. To prepare for the exercise, students should read the relevant lecture material and textbooks, as well as the accompanying laboratory material. Each exercise consists of two components:
    - Demonstration of Examples: At the beginning of the laboratory exercise, the instructor demonstrates examples using the educational tool. The instructor should utilize the system's potential to engage students, as otherwise, the exercises would merely represent a different approach to theoretical presentation. In line with the principles of active learning, an interactive approach to the demonstration involves engaging students so that they are not just passive observers. The easiest way to include students during the demonstration is by frequently asking "what if" questions and prompting them to predict the results.
    - Laboratory Assignment: After the demonstration is completed, students receive appropriate laboratory tasks that they complete independently.

By applying this strategy, students show a high level of motivation and actively participate in the entire process and discussion. Another advantage of the presented web tool is that once students become familiar with it, they can use it independently after class as an additional resource for solving homework assignments and seminar papers.

Experiments and evaluation

This study employs a descriptive research design that relies on quantitative data. The aim of the study is to conduct a quantitative assessment of the contribution to learning through the use of the developed web-based tool. The research instruments include a controlled experiment to test the efficiency of the software tool and a survey to gather user feedback on satisfaction. The objective of the survey is an objective assessment of the tool's usability.

For the experiment, a purposive (nonprobabilistic) sampling technique was applied (Vehovar et al., 2016). The selected sample consisted of students who had not yet attended the Machine Learning course and who had no experience with using the SVM algorithm but had general knowledge about the machine learning concept. A total of 38 undergraduate students from the Faculty of Technical Sciences in Kosovska Mitrovica and the Toplica Academy of Vocational Studies in Prokuplje were selected. For the experiment, the selected sample of students was divided into two groups: control and experimental. The allocation of students to the groups was random. Both the experimental and control groups consisted of 19 students each.

Experiment methodology

The experiment consisted of three phases: pre-testing, training, and post-testing (Dugard and Todman, 1995). The pre-test questionnaire was designed with questions related to general information about classification algorithms and the SVM algorithm. This questionnaire assesses the prior knowledge of all participants on the given topic. It contained eight multiple-choice quiz questions and six questions requiring standard written answers. Quiz questions were scored with 5 points each, while the standard questions were scored with 10 points each (or less if the answer was partial).

The post-test questionnaire was similar in structure to the pre-test questionnaire, but the questions focused solely on the SVM algorithm. The post-test was used to assess the knowledge gained after the training phase. The training process for the control group involved traditional teaching, while the learning strategy for the experimental group is described in detail in the Case Study section. Traditional teaching was also based on the theory-examples-exercises paradigm. For each topic, theoretical concepts were first presented during lecture sessions. Laboratory exercises were designed to provide a more detailed

explanation of the topics covered in lectures, without the use of an educational web tool, but rather through practical examples applying the hands-on tasks pedagogical method. The instructors and examiners were the same for both groups.

Survey methodology

In addition to the controlled experiment, it was necessary to conduct a survey on the advantages and significance of the auxiliary learning system. This process aimed to assess students' experiences with the alternative learning method using the auxiliary tool and their perception of the software system's effectiveness. For this purpose, the standardized System Usability Scale (SUS) was used. SUS is a quick and reliable technique for measuring system usability (Brooke, 1996). It consists of a standard questionnaire with 10 questions. For each question, respondents select a statement indicating their level of agreement or disagreement with the statement on a 5-point Likert scale. SUS is generally administered after the respondent has had the opportunity to use the system being evaluated but before any other testing or discussion takes place. If a respondent feels unable to answer a particular item, they should mark the central point on the scale.

Experiment results

For this experiment, quantitative data were collected based on the established methodology, and descriptive statistics were used for their analysis. To reliably examine the existence of statistically significant differences in the achieved results between students in the control and experimental groups, the ANCOVA statistical method was used. The analyses were conducted using SPSS software (version 25). ANCOVA (Analysis of Covariance) is used to determine the presence of significant differences between two or more independent groups concerning a dependent variable. By isolating the effect of a categorical independent variable on the dependent variable, researchers can draw more accurate and reliable conclusions from their data. ANCOVA seeks differences in adjusted mean values.

Individual differences between students in academic abilities can significantly impact learning outcomes. Even within the same group, there can be significant variations in students' prior knowledge. This variation can obscure the true impact of the applied method on the learning outcomes or results. By including pre-test results as a covariate in the ANCOVA model, it is possible to more clearly and precisely understand whether students' success in the post-test was due to the applied teaching method. In this statistical model, the post-test result is taken as the dependent variable, the teaching method as the categorical factor, and the pre-test result as the covariate.

- H_0 - Null Hypothesis: There is no significant difference in the adjusted mean values of the post-test results between the control and experimental groups.
- H_1 - Alternative Hypothesis: There is a significant difference in the adjusted mean values of the post-test results between the control and experimental groups.

The achieved post-test results of the students are shown in Figure 12.

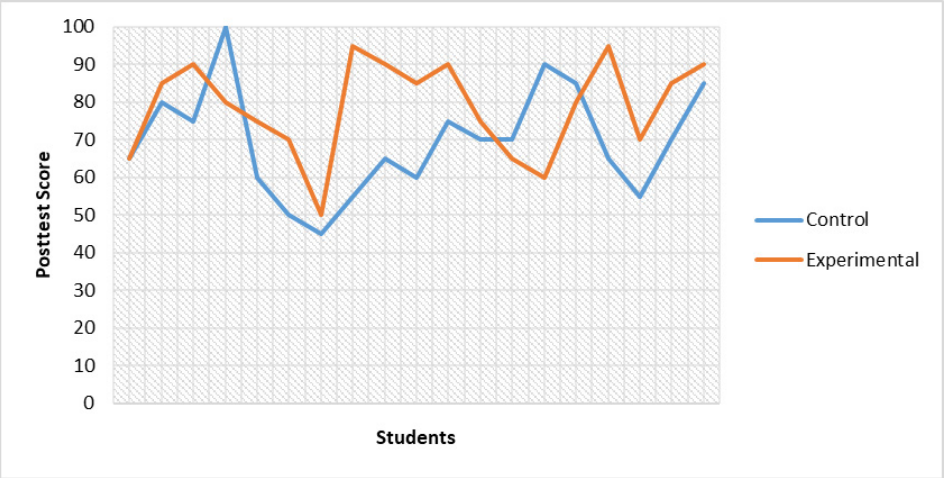

Figure 12. Achieved post-test results

Descriptive statistics for the dependent variable (post-test results) are presented in Table 1. Here, the mean values and standard deviations of the results for each group are shown.

Table 1. *Descriptive Statistics for Dependent Variable: Posttest*

Group	Mean	Std. Deviation	N
control	69,4737	14,22974	19
experimental	78,6842	12,67567	19
Total	74,0789	14,08734	38

The results of Levene's Test for Homogeneity of Variances are shown in Table 2. This test evaluates whether the variances between groups are approximately equal.

Table 2. *Levene's Test of Equality of Error Variances*[a]

Dependent Variable: Posttest

F	df1	df2	Sig.
,130	1	36	,721

a. Design: Intercept + Pretest + Group

The main part of the ANCOVA test results is shown in Table 3. This table presents the effects of the test between subjects, focusing on the level of significance concerning the independent variable.

Table 3. *Tests of Between-Subjects Effects*

Dependent Variable: Posttest

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	892,054[a]	2	446,027	2,420	,104	,121
Intercept	3024,956	1	3024,956	16,413	,000	,319
Pretest	86,133	1	86,133	,467	,499	,013
Group	868,456	1	868,456	4,712	,037	,119
Error	6450,710	35	184,306			
Total	215875,000	38				
Corrected Total	7342,763	37				

a. R Squared = ,121 (Adjusted R Squared = ,071)

A comparison of the mean values of post-test results between the control and experimental groups is presented in Table 4.

Table 4. *Pairwise Comparisons*

Dependent Variable: Post

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
control	experimental	-9,674*	4,456	,037	-18,721	-,627
experimental	control	9,674*	4,456	,037	,627	18,721

Based on estimated marginal means

*. The mean difference is significant at the ,05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Survey results

The SUS provides a score that represents a composite measure of the overall usability of the system under study. To calculate the score, first sum the contributions from each item. Contributions range from 0 to 4. For questions 1, 3, 5, 7, and 9, the contribution is the scale position minus 1. For items 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position. The sum of contributions is then multiplied by 2.5 to obtain the overall score. SUS scores range from 0 to 100. Bangor et al. (2008) experimentally demonstrate that software with SUS scores below 50 is "unacceptable," while scores above 70 indicate "acceptable" usability. Scores between 50 and 70 are considered "marginally acceptable."

Following the completion of the post-test, students in the experimental group who had the opportunity to use the educational tool received the SUS questionnaire. The results of this survey, processed using the described technique, are presented in Table 5.

Table 5. *Responses to Individual System Usability Scale Statements*

	Statement	M	SD
1	I think that I would like to use this system frequently.	3,47	0,84
2	I found the system unnecessarily complex.	2,63	0,90
3	I thought the system was easy to use.	3,37	0,68
4	I think that I would need the support of a technical person to be able to use this system.	2,89	0,99
5	I found the various functions in this system were well integrated.	3,63	0,68
6	I thought there was too much inconsistency in this system.	2,74	0,81
7	I would imagine that most people would learn to use this system very quickly.	3,53	0,70
8	I found the system very cumbersome to use.	2,58	1,02
9	I felt very confident using the system.	3,42	0,84
10	I needed to learn a lot of things before I could get going with this system.	2,32	1,06

Discussion

The results of the post-test show that the average score of students in the experimental group was higher than that of the control group. This is clearly seen in Table 1, which displays the descriptive statistics, revealing an average score of 78.68 for the experimental group compared to 69.47 for the control group. However, it was crucial to prove that this improvement in the experimental group's scores was statistically significant. Therefore, Levene's test was conducted initially to test for equality of variances. The results of this test, which are shown in Table 2, with Sig. = 0.721, indicate that there was no significant difference in variance between the control and experimental groups because the significance level exceeded the threshold of 0.05. Thus, based on the pre-test results, it was established that the formed groups did not statistically differ before the start of the training.

Finally, the results of the ANCOVA analysis (Table 3) demonstrated a statistically significant impact of using the instructional method with the supplementary software tool on the post-test results. With F (1, 35) = 4.712 and a p-value of 0.037 < 0.05, the null hypothesis (H0) is rejected, supporting the alternative hypothesis (H1) that there is a significant difference in adjusted mean post-test scores between the control and experimental groups.

Table 4 compares the mean post-test scores, showing a difference of 9.67% between the mean scores of the experimental and control groups.

The usability assessment of the system was conducted using the SUS technique, and the results of this survey are presented in Table 5. This table displays the mean scores for each question. By summing these mean scores, a total contribution of 30.58 was obtained. As described, this contribution is multiplied by 2.5 to yield a total SUS score of 76.45. Therefore, since the final score is >70, the implemented tool is considered acceptable on the SUS usability scale.

Finally, it is important to highlight potential threats to the validity of this empirical assessment.

These threats can be classified as internal, construct, and external validity.

Internal validity threats primarily concern causal questions regarding the presented results. It's worth noting that none of the students who participated in the experiment had prior knowledge of the study preparation. However, if anyone somehow obtained information about the experiment, it could have led to bias in evaluation. Since collaboration among students is important for the learning process, it cannot be accurately assessed whether one group of students has better or worse communication and teamwork skills. To mitigate this threat, both groups had the same instructors.

Construct validity threats usually relate to potential errors in assessment. This type of threat can be influenced by the evaluation method used. For evaluating this tool, a pretest-posttest method was applied. Different results may have been obtained using different assessment methods. To reduce the impact of this threat on the assessment of tool effectiveness, the standard SUS technique, which is widely accepted for evaluating usability levels, was applied.

External validity threats concern the extent to which findings from the experiment can be generalized and how relevant they are to other students beyond this study. To mitigate this threat, students from two different higher education institutions participated in the experiment. However, for generalization, one should consider the sample size of students, geographic distance between participating universities, socio-cultural differences, and the complexity of tests assigned to students. Thus, the results presented in this study cannot be generalized until more data are obtained from other empirical evaluations involving different universities and students.

Conclusion

Acquiring skills and knowledge in machine learning is a crucial aspect of academic education for IT engineers. Teaching complex algorithms in this field should consider the use of innovative tools and methodologies developed to enhance and supplement the learning and teaching processes. The web application for learning Support Vector Machines (SVM) represents a significant advancement in computer engineering education, providing intuitive and interactive ways to understand and apply SVM algorithms. Developed using state-of-the-art web technologies, the proposed application promises to become a valuable resource for students, educators, and researchers in the field of machine learning. This study analyzes the impact of implementing a new interactive learning method based on the developed web application on learning outcomes.

As a result of using the visual software tool in machine learning classes, student engagement levels have increased. Visualization of the complex SVM algorithm has enabled students to better understand the workings of the algorithms, down to finer details. These claims are substantiated by a conducted experiment aimed at quantitatively assessing the learning contributions using the developed web-based tool. Research instruments included a controlled experiment to verify the efficiency of the software tool and a survey to collect user satisfaction feedback. The experiment results show that students who used the tool in their learning (experimental group) have a better understanding of the taught topics compared to students whose learning was based solely on traditional methods (control group). Through the application of the ANCOVA statistical method, the study reliably demonstrated a statistically significant difference in outcomes between the control and experimental groups.

The usability assessment of the proposed system was evaluated using the SUS technique. Based on the final survey results, it can be stated that the implemented tool was rated as acceptable on the SUS usability scale.

In future work and research, a broader assessment of the tool with a greater number of students from various universities should be considered. In addition, future work will be valuable to analyze the advantages and limitations of the developed web application compared to similar existing tools. Further enhancements to the proposed system could involve the addition of modules for learning other machine learning algorithms.

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Author Contributions

Conceptualization, N.J., S.J. and S.S.; methodology, N.J., S.J. and S.S.; software, N.J. and S.J.; formal analysis, S.S., D.M. and N.S.; writing—original draft preparation, N.J. and S.S.; writing—review and editing, S.J., D.M. and N.S. All authors have read and agreed to the published version of the manuscript.

Conflict of interests

The authors declare no conflict of interest.

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Cryptography in Organizing Online Collaborative Math Problem Solving

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Abstract: The aim of this study is to examine the potential of cryptographic techniques in enhancing the organization of online group work for solving mathematical problems, while applying differentiated instruction. Engaging students in mathematics often requires additional motivational strategies and compelling incentives for sustained effort. Online group work presents a valuable opportunity for collaboration and intensive communication in solving mathematical problems. However, it also poses challenges, particularly concerning academic integrity and the risk of unauthorized copying. To address these issues, this study proposes the integration of cryptographic protocols with differentiated instruction in online collaborative tasks. Specifically, various levels of problem-solving assistance are made accessible only when the majority of the group members reach a consensus. Assistance is unlocked through the submission of individual cryptographic key segments, assigned by the instructor. A group password-required to access incremental guidance-can be generated only when a sufficient number of key segments have been submitted. This mechanism facilitates progress monitoring and fosters group accountability. The paper illustrates this approach with an example from mathematics instruction, supported by a Python-based software tool designed to aid collaborative learning. The software employs Lagrange interpolation to generate unique key parts for each participant. The method was piloted with six pre-service teachers in Serbia, and the qualitative findings are discussed alongside implications for educational research and practice.

Keywords: *collaborative learning, cryptographic techniques, mathematics differentiated instruction, online group work, problem-solving strategies.*

Introduction

The Internet and digital technologies have profoundly transformed education over the past decade, reshaping the landscape of distance and online learning (Adedoyin and Soykan, 2023). Virtual learning environments offer numerous advantages, such as flexibility, international collaborations, enriched educational experiences, increased student engagement, and the potential for anonymity (Allen et al., 2002). These benefits, combined with improved faculty development and more comprehensive feedback mechanisms, have underscored the growing importance of online education in contemporary pedagogy (Appana, 2008). Nevertheless, significant challenges remain—particularly in maintaining student motivation and preventing disengagement in virtual learning settings (Lee, 2010).

One area where innovation may address these challenges is in online mathematics education. The integration of cryptography within this domain holds promise, as it may increase student motivation by introducing an element of intrigue and intellectual challenge (Koblitz, 1997). Although cryptography is traditionally associated with securing data, its educational potential—especially in fostering collaborative problem-solving—has been largely overlooked. This paper seeks to bridge that gap by proposing a novel approach to organizing online collaborative math problem-solving through the use of cryptographic techniques.

Collaborative problem-solving (CPS) plays a crucial role in mathematics education, fostering essential 21st-century skills and enhancing student engagement (Felmer, 2023). By working together to tackle complex problems, students develop critical thinking, communication, and teamwork abilities, all of which are vital in today's interconnected world. This approach not only deepens their mathematical understanding

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but also prepares them for real-world challenges that require collaborative efforts and innovative solutions.

The COVID-19 pandemic accelerated digital transformation in education, compelling institutions to rapidly adopt online platforms and practices that otherwise might have taken years to implement (Adedoyin and Soykan, 2023). This transition highlighted the potential of collaborative learning in virtual settings, offering both academic and social benefits to students (Đorđević and Milutinović, 2021). Research suggests that students working collaboratively often outperform individuals working alone, as shared goals promote accountability and active participation (Johnson and Johnson, 1999). Cooperative learning also supports students' social and psychological needs, fostering interaction and promoting self-directed learning (Slavin, 1995).

Within the context of online math education, group work has emerged as an effective strategy for developing key skills. According to the ISTE standards (International Society for Technology in Education, 2016), students should engage with digital tools to enhance problem-solving, decision-making, and global collaboration. However, the effectiveness of online group work is frequently hampered by issues such as academic dishonesty, intra-group conflict, and unequal participation (Vienović and Adamović, 2013). Cryptography offers a potential solution to these issues by enabling secure, consensus-based collaboration. By assigning unique cryptographic keys to each participant and requiring group agreement to unlock portions of problem-solving tasks, the model can mitigate cheating and foster cooperation.

This paper introduces and explores a cryptographic model designed to structure and support online collaborative mathematics problem-solving. It examines the model's potential to enhance motivation, ensure academic integrity, and promote meaningful collaboration, thereby addressing a critical gap in the existing literature (Đorđević and Milutinović, 2021).

Research Objective and Question

This study aims to evaluate the effectiveness of a cryptographic model in facilitating collaborative problem-solving and differentiated instruction among pre-service teachers. Specifically, the research seeks to answer the following question:

- How does the integration of cryptographic techniques in online collaborative math problem-solving with differentiated instruction influence pre-service teachers' engagement, mathematical understanding, and collaboration?

Scope and Significance

This study focuses on the design, implementation, and evaluation of a cryptographic model for online collaborative mathematical problem-solving, embedded within a differentiated instruction framework for pre-service teachers. The model assigns unique cryptographic keys to each participant, requiring group consensus to unlock progressive levels of problem-solving support. The significance of this research lies in its potential to:

- Enhance student motivation by introducing differentiated instruction elements into the learning process;
- Protect academic integrity by mitigating issues such as answer copying and uneven participation;
- Foster effective collaboration and the development of 21st-century skills, including critical thinking, communication, and teamwork.

By addressing these aspects, the study contributes to the growing body of knowledge on integrating cryptography into educational practices, offering insights into innovative methods for engaging students and promoting deeper learning in online environments.

Literature review

Online education

Online education refers to the process of delivering educational content through Internet-based platforms (Lee, 2010). Owing to the flexibility and convenience of such courses, research has highlighted their potential and positive impact on student learning outcomes (Allen et al., 2002). Online learning encompasses a variety of computer-based tools, including multimedia resources, simulations, and educational games across diverse subject areas (Keengwe and Kidd, 2010). Beyond content delivery, it aims

to foster metacognitive, reflective, and collaborative skills. Self-directed learning and autonomy in managing learning experiences also play a vital role in online environments, contributing to improved academic performance (Keengwe and Kidd, 2010). Mandić et al. (2018) suggested that modular teaching systems, integrating face-to-face, web-based, and supervised instructional methods, promote independent learning, foster curiosity, and encourage active student engagement, contributing to intellectual growth. This is a form of blended or hybrid learning that incorporates elements of both traditional and online learning.

In higher education, online environments are typically characterized by active learning and student-centered strategies (Barker, 2003). However, maintaining faculty engagement is a key challenge for institutions offering online learning. Many educators are hesitant to transition from traditional courses to online formats, often citing a lack of institutional support, training, and resources (Keengwe et al., 2009). Faculty engagement is further influenced by factors such as perceived usefulness, ease of use, and digital competencies (Milutinović, 2020).

Obstacles to online learning adoption include faculty workload, technical issues, lack of administrative backing, and concerns regarding course quality (Nelson and Thompson, 2005). Additionally, faculty members often face expanded roles in online settings, taking on responsibilities as mentors, coaches, and counselors (Gratz and Looney, 2020). To address these challenges, institutions should provide robust technical support and allocate dedicated time for faculty to develop and manage online courses. Faculty must adapt to new roles, assuming responsibilities as facilitators, designers, and technologists in online learning environments (Panda and Mishra, 2007). Without institutional support, educators face increased pressure to manage these roles independently, further complicating online instruction (Williams, 2003). Therefore, education institutions should provide streamlined technical solutions to support online group work, thereby reducing faculty workload and enhancing instructional efficiency.

Collaborative learning and problem-solving

Collaborative learning is an instructional approach in whichindividuals work jointly, sharing responsibility and authority to achieve common objectives (Johnson and Johnson, 1999). It emphasizes consensus-building over competition, promoting social skills and teamwork among students (Cohen and Cohen, 1991). Extended group collaboration encourages community building, as students often stay connected beyond classroom activities (Bean, 1996). This interaction enhances social support networks, allowing students to better understand differences and work through social challenges (Cohen and Willis, 1985).

Sherman (1991) highlights that collaborative learning provides effective environments for conflict resolution, fostering social strategies to address disputes (Johnson and Johnson, 1990). Collaboration helps students develop responsibility for their peers, leading to stronger interpersonal bonds (Bonoma et al., 1974). Collaborative learning also enhances cognitive skills, as students are actively engaged in discussing and problem-solving together (Webb, 1980). The structure of collaboration allows teachers to assess students' thinking processes, offering opportunities for further support (Peterson and Swing, 1985).

Collaborative learning environments reduce student anxiety, especially in unfamiliar settings, fostering better engagement and motivation (Kessler et al., 1985). The benefits of collaboration are well-documented, leading to improved academic outcomes, stronger relationships, and enhanced social and psychological well-being (Laal and Ghodsi, 2012).

Tian and Zheng (2024) suggest employing online collaborative problem-solving (CPS) techniques to enhance students' cognitive and emotional learning outcomes. To further improve students' social learning performance, they advocate for instructors to thoughtfully design collaborative scaffolding that actively engages students in purposeful and constructive online CPS activities.

Collaborative Problem-Solving (CPS) is underpinned by several key theoretical frameworks that emphasize the importance of social interaction and active engagement in learning. Lev Vygotsky's Social Constructivism posits that knowledge is constructed through social interactions, highlighting concepts such as the Zone of Proximal Development (ZPD) and scaffolding (Vygotsky, 1978). The ZPD represents the gap between what a learner can do independently and what they can achieve with guidance from more knowledgeable others. Scaffolding refers to the support provided to learners that enables them to perform tasks they cannot complete alone, fostering cognitive development through collaborative efforts.

Additionally, Piaget's theory of individual constructivism contributes to understanding CPS by focusing on cognitive development through peer interactions. His work suggests that peer cooperation is a

significant social relation that supports cognitive growth, especially when peers with different perspectives engage in problem-solving together. This interaction can lead to cognitive conflict, which is essential for learning and development (Baucal et al., 2023).

Furthermore, Problem-Based Learning (PBL) shares foundational principles with CPS, emphasizing experiential and situated learning. PBL is grounded in theories of experiential learning, contextualized learning, collaborative learning, and self-regulated learning (Chen, 2022). It posits that learning is most effective when it occurs within the context in which knowledge will be applied, encouraging learners to take responsibility for their learning processes through active problem-solving.

Online collaborative group work

Historically, collaborative learning was restricted to in-person settings due to logistical constraints, such as finding a common time and place for students to meet (Kimball, 2002). However, the rise of Internet-based communication has expanded the possibilities for online collaboration (Collis, 1996). Learning management systems like Moodle and Google Classroom provide tools for synchronous and asynchronous discussion, enabling remote group work (Paloff and Pratt, 1999). These platforms have enhanced peer interaction, even among distance learners who had limited opportunities for collaboration before (Piezon and Ferree, 2008).

Online group work, however, presents challenges that often hinder student participation. Concerns about unequal contributions, managing group members' expectations, and the reduced flexibility of collaborative schedules contribute to student reluctance (Brindley et al., 2009). While technology enables collaboration, it also imposes constraints that can make students apprehensive about group work. Milutinović (2024a) found that positive attitudes toward collaboration improved both perceived usefulness and enjoyment of programming among primary school students in Serbia. This suggests that a positive attitude toward collaboration enhances students' perception of educational value and increases their enjoyment of the learning process, underscoring the importance of cultivating positive experiences in collaborative work.

Differentiated instruction in mathematics

Vygotsky's concept of the Zone of Proximal Development (ZPD) highlights the range of tasks that learners can perform with appropriate guidance. Differentiated instruction applies this by tailoring support to help students progress within their ZPD, facilitating effective learning experiences. Tomlinson's Differentiated Instruction framework (Tomlinson, 2005) provides a structured approach to differentiation, focusing on modifying content, process, product, and learning environment based on students' readiness levels, interests, and learning profiles. This model serves as a practical guide for implementing differentiated strategies in mathematics education to address student diversity effectively (Kurnila and Juniati, 2025). Differentiated instruction in mathematics is an inclusive approach that tailors teaching strategies to meet diverse student needs (Gervasoni and Lindenskov, 2010). Hackenberg et al. (2021) defined differentiated instruction as the proactive adaptation of teaching strategies to align with students' mathematical thinking while fostering a unified classroom community. Through analysis of 10 episodes across experiments, they identified five teaching practices that facilitate this approach: utilizing research-based insights into students' mathematical reasoning, offering purposeful choices and multiple pathways, engaging responsively during group activities, monitoring small group dynamics, and leading whole-class discussions that integrate diverse perspectives.

Research in mathematics education has highlighted the multifaceted nature of differentiation, emphasizing its importance in curriculum design, assessment, remote learning environments, teacher knowledge, and inclusive practices. Saxe et al. (2013) conducted a study where fourth-grade students received differentiated instruction using number lines to learn fractions and integers, resulting in significantly greater learning gains compared to those in standard classrooms. Similarly, Chamberlin and Powers (2010) observed that prospective teachers in differentiated mathematics courses exhibited statistically significant improvements from pretest to posttest compared to their counterparts in traditional classes.

Effective differentiation is increasingly critical in creating inclusive classrooms that accommodate students with varying academic abilities. As educational expectations evolve, teachers are required to implement pedagogies that foster success for all learners, including those with low achievement levels (Shernoff et al., 2011). Computerized systems and differentiation as part of a broader educational context positively impact students' language and math performance in primary education (Deunk et al., 2018).

Despite increased awareness of differentiated instruction, teachers often struggle to implement these approaches in practice (Bobis et al., 2019). Teachers have reported gaining a better understanding of differentiation through targeted professional learning and enriched curricula, although barriers to effective implementation persist (Hayden et al., 2023). Research suggests that further support is needed to overcome the constraints limiting teachers' ability to differentiate effectively.

Cryptography in organizing online collaborative group work

Cryptography, derived from the Greek words *kryptós* (hidden, secret) and *graphein* (to write), plays a crucial role in securing data (Dooley, 2008). Modern cryptography systems, including symmetric (Data Encryption Standard – DES, and Advanced Encryption Standard – AES), and asymmetric (Rivest-Shamir-Adleman – RSA) encryption, are widely used to protect privacy and secure communications (Vienović and Adamović, 2013). In education, cryptography can be leveraged to organize online collaborative group work.

A cryptographic system based on Galois fields has potential applications for structuring online collaboration. Đorđević and Milutinović (2021) proposed a model using the Galois field GF (2^8), commonly used in the AES system, to secure group decision-making. The model applies the Lagrangian interpolation polynomial to generate key parts for group members. Each student is assigned a portion of the cryptographic key, and a two-thirds majority is required to reconstruct the original key.

In this model, if fewer than two-thirds of the group members participate, the key cannot be calculated, preventing unauthorized actions. The model ensures fairness in group decisions by distributing key ownership among participants. If a two-thirds majority agrees, the key can be reconstructed, allowing the group to perform the desired action. This system not only secures the decision-making process but also addresses potential issues related to uneven participation in online group work (Đorđević and Milutinović, 2021).

Materials and Methods

Aim of the Study

This study aims to evaluate the effectiveness of a cryptographic model in enhancing collaborative problem-solving among pre-service teachers. The model is designed to support differentiated instruction in online group settings by providing structured assistance levels to enhance engagement and mathematical understanding.

Research Design

A qualitative case study approach was employed to gain an in-depth understanding of how the cryptographic model influences collaborative problem-solving and differentiated instruction among pre-service teachers. This design is appropriate for exploring complex phenomena within their real-life contexts, allowing for a comprehensive examination of participants' experiences and interactions with the model.

Participants and Sampling

The study involved a purposive sample (Ahmad and Wilkins, 2024) of six pre-service teachers from the Faculty of Education in Jagodina. Purposive sampling was chosen to select individuals who possess prior knowledge of linear equations and familiarity with various solution methods, including graphing, elimination, and substitution. This criterion ensured that participants had the necessary background to engage meaningfully with the collaborative tasks and the cryptographic model.

Data Collection Tools and Procedures

Data were collected through multiple methods to ensure a rich and comprehensive understanding of the participants' experiences:

1. Observations: Participants engaged in a week-long collaborative task focusing on solving a system of linear equations. Their interactions, problem-solving strategies, and use of the cryptographic model were observed and documented.
2. Interviews: Semi-structured interviews were conducted with each participant post-intervention to

gather insights into their perceptions of the cryptographic model's effectiveness, its impact on their collaborative problem-solving abilities, and its role in supporting differentiated instruction.

3. Artifacts Analysis: Participants' work products, including solution processes and communication logs, were collected and analyzed to triangulate data from observations and interviews.

Data Analysis Techniques

Thematic analysis was employed to analyze qualitative data from observations, interviews, and artifacts. This involved coding the data to identify recurring themes and patterns related to the research objectives. The analysis focused on understanding how the cryptographic model influenced collaborative dynamics, supported differentiated instruction, and impacted participants' mathematical understanding.

Justification of Methods

The qualitative case study design was selected for its strength in exploring complex educational interventions within their natural settings (Ancker et al., 2021). Purposive sampling ensured that participants had the requisite background to engage with the study's tasks, aligning with the goal of assessing the cryptographic model's effectiveness among individuals with foundational knowledge of linear equations. The combination of observations, interviews, and artifact analysis provided a comprehensive data set, allowing for triangulation and enhancing the validity of the findings. These methods collectively align with the research goals by facilitating an in-depth exploration of the cryptographic model's impact on collaborative problem-solving and differentiated instruction among pre-service teachers.

Mathematical foundation and the development of user-friendly application

A common mathematical foundation for forming a cryptographic system is Galois fields and their extensions. The model used in this paper is based on the finite Galois field GF (2^8), which is most commonly used in AES systems (Daemen and Rijmen, 2002; Desoky and Ashikhmin, 2006; Murphy and Robshaw, 2002). In such cryptographic systems, a byte is considered as an element of a binary finite field defined by the irreducible "Rijndael" polynomial $P(x) = x^8 + x^4 + x^3 + x + 1$ (Murphy and Robshaw, 2002). This field is characterized by a large number of inverse operations, using arithmetic modulo 2^8. For example, AES uses the inverse element operation in relation to multiplication in the field GF (2^8) (Desoky and Ashikhmin, 2006). Furthermore, this field includes operations on polynomials of arbitrary degree, with coefficients ranging from 0 to 255 from the field GF (2^8) (Daemen and Rijmen, 2002). One such operation is the Lagrange interpolation formula.

The challenge of constructing a continuous function from discrete data arises frequently in mathematical analysis, especially when data manipulation requires estimates beyond the provided dataset. A commonly preferred method for addressing this issue is interpolation, where the goal is to construct an approximation function that exactly matches the values of the original, typically unknown, function at the given data points. In practical computational applications, the interpolation problem can be stated as follows: given the function values at a finite set of points, determine the function's value at an intermediate or specified argument (Hussien, 2011).

Let the function f be defined by its values $f_x = f(x_k)$ at discrete points x_k where $k = 0,1,2, \dots, n$. Without loss of generality, we assume that $a \leq x_0 \leq x_1 \leq \dots \leq x_k \leq b$. If the points x_k are taken as interpolation nodes and $\varphi_k(x) = x^k$, $(k = 0,1, \dots, n)$ is set, we arrive at the interpolation problem for the function f using an algebraic polynomial. Let this polynomial be denoted as P_n (Milovanović, 1988), i.e.:

$$P_n = a_0 + a_1 x + \dots + a_n x^n$$

Lemma 1 (Lagrange interpolation polynomial) (Kovács and Kovács, 2005): The polynomial is unique and can be represented in the form:

$$P_n(x) = \sum_{k=0}^{n} f(x_k) L_k(x)$$

where:

$$L_k = \prod_{k,j=0, k \neq k}^{n} \frac{x - x_k}{x_j - x_k}$$

The previously discussed concepts are now applicable to cryptographic decision problems within a group setting, such as a group of six members where four parts are required to generate the key. For a given integer , that lies in the range $0 \leq a \leq 255$, random integers $r_1, r_2, \ldots, r_3$ are generated within the range of 0 to 255. For these given values, a polynomial $f(x)$ is formed over the field GF (2^8):

$$f(x) = a + r_1 x + \ldots + r_3 x^3$$

It is evident that $f(0) = a$. Subsequently, the values $f(1), \ldots, f(6)$, are calculated, where these values represent elements of the finite field GF (2^8) with operations conducted according to the rules of that field. Next, ordered pairs $p_1 = (1, f(1)), \ldots, p_6 = (6, f(6))$ are formed, and a function is implemented that, using any random selection of four out of the six pairs, calculates $f(0)$ (which equals a) through the Lagrange interpolation formula.

The above principles can be applied to a group of six individuals who must reach a decision by a two-thirds majority to execute an action protected by a key. If any one member possesses the entire key, that individual can unilaterally make the decision, similar to the case where no key exists. Conversely, if the key is divided into six parts, each assigned to an individual, it is possible for five members to agree to execute the action while the sixth key holder withholds their part, creating an unfair situation in group dynamics.

When the key is represented as an integer a in the range of 0 to 255, pairs $p_1, \ldots, p_6$ can be formed as previously described, with one pair allocated to each group member. If any four key holders decide to proceed, they can utilise the Lagrange interpolation polynomial to compute . However, if three or fewer members contribute their pairs, they cannot successfully calculate the key using the Lagrange interpolation polynomial, thus preventing the execution of the desired action. Therefore, the key can be divided into six parts, allowing for the calculation of the key with any four parts, while fewer than four parts will yield an incorrect key.

For the purpose of studying the implementation of cryptography in organizing online collaborative group work, the authors developed user-friendly software tailored for both teachers and students. The software, built using the Python programming language, was designed based on the mathematical foundations presented above and algorithms presented by Đorđević and Milutinović (2021). Milutinović (2024b) argues that Python is a versatile, high-level language supporting various programming paradigms, making it ideal for implementing different algorithms. Its extensive library is especially useful for mathematical topics such as algebra, calculus, and number theory, contributing to its widespread use today.

The interface of the developed software facilitates seamless interaction while applying the cryptographic model, ensuring that group work is securely managed and decision-making is fair and transparent.

Procedure

The method implemented in this study can be used with students at all levels of education and consists of the following steps:

Step 1 - Key Construction: The professor constructed ordered pairs based on a selected key that represents sections of the key relevant to decision-making in group work. Each participant received three ordered pairs corresponding to three different levels of help, facilitating differentiated online group problem-solving. Before accessing any level of assistance, at least two-thirds of the group must agree to use their portion of the key.

Step 2 - Differentiated Instruction: The cryptographic model is straightforward to implement for administering differentiated instruction during online group work. Assistance is divided into three levels-referred to as “first,” “second,” and “third” help-for a particular task worth 10 points (Đorđević and Milutinović, 2021). Each level of assistance is safeguarded by a unique key, divided into as many ordered pairs as there are group members.

Point System and Help Retrieval:

First Help: If students require more guidance, they may use their ordered pairs to unlock the “first help,” which provides gentle direction toward the solution. Opening this assistance results in a loss of 2 points for each group member, which is recorded.

Second Help: If the “first help” is insufficient, students can access the “second help” for more detailed instructions and completed examples related to the problem, resulting in a 5-point deduction for each group member.

Third Help: Should students still struggle, they can utilize their ordered pairs to unlock the “third help,” which offers comprehensive instructions and part of the solution, incurring an 8-point penalty. Alternatively,

if students feel unprepared, they may directly access the "third help" without using the first two levels.

Assessment and Feedback: The professor reviews the last level of assistance requested by the group. Points are awarded based on the level of help accessed. For example, if the "third help" is used immediately, students lose 8 points. If the group accesses the "first" and "second helps" but does not use the "third," they only incur a 5-point penalty, as points are not cumulative.

At the conclusion of the assignment, the authors conducted semi-structured interviews with the participants to gain insights into their experiences and perspectives regarding the collaborative problem-solving process. This qualitative approach aimed to understand how the structured assistance influenced their learning and engagement in the task. The interviews provided an opportunity for participants to articulate their thoughts, feelings, and reflections, enriching the data collected and contributing to a deeper understanding of the effectiveness of the implemented method.

Group assignment example

For their assignment, the pre-service teachers worked on solving the system of linear equations.

Assignment: For the given system of linear equations

$$-x - 2y + 14z = 8$$
$$3x - 5y - 7z = 9$$
$$4x - 2y - 3z = 24$$

find the solution (x, y, z).

Students had already mastered the basics of solving linear equations and systems of equations in their Basic Mathematics course at the Faculty. The goal of this task was to enhance their skills in solving systems of linear equations using substitution.

The group work was organized using the institution's Learning Management System, Moodle, which enabled the formation of collaborative student groups for submitting a shared assignment. The professor could assign specific activities to designated group, ensuring that group members possessed similar mathematical competencies. Interaction within the group was facilitated through forums, wikis, and databases, with access restricted to group members. The professor also controlled whether students could view additional resources.

The group assignment in Moodle for solving the given system of linear equations is illustrated in Figure 1.

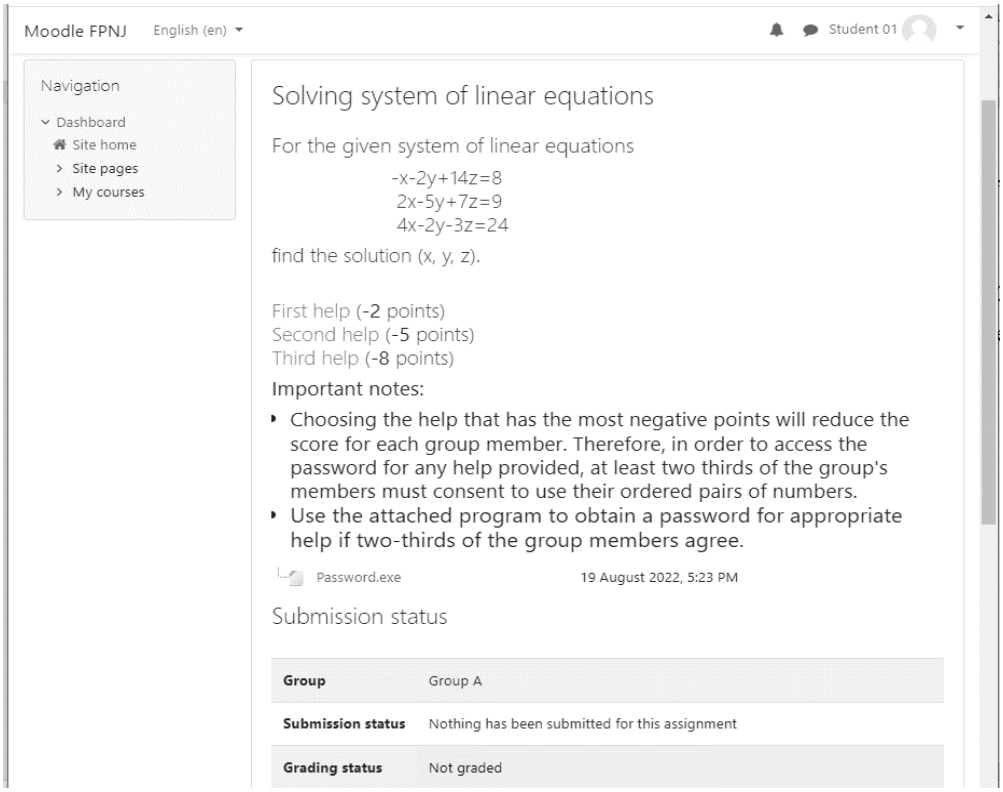


Figure 1. Moodle group assignment

Example of help retrieval

If students were unable to solve the problem collaboratively, they could decide whether to use any of the available assistance (i.e., first, second, or third help). Each group member's score would decrease if they opted for assistance, with penalties for using help. For example, to unlock the "first help," the password was set to 38, and the ordered pairs assigned to students were: (3, 226), (4, 124), (1, 212), (5, 129), (2, 156), and (6, 210), with the password, which was known known only to the teacher. Since selecting assistance would result in a decline in each group member's score, it was necessary for at least two-thirds of the group members to agree before using their ordered pairs to decipher the password for any assistance. Once two-thirds of the group reached consensus, they utilized the user-friendly software developed for this study (see Figure 2) to obtain the correct password for the selected help.

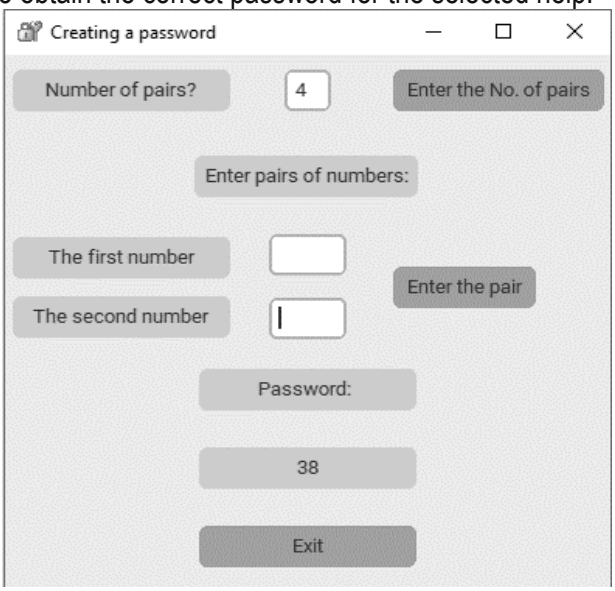
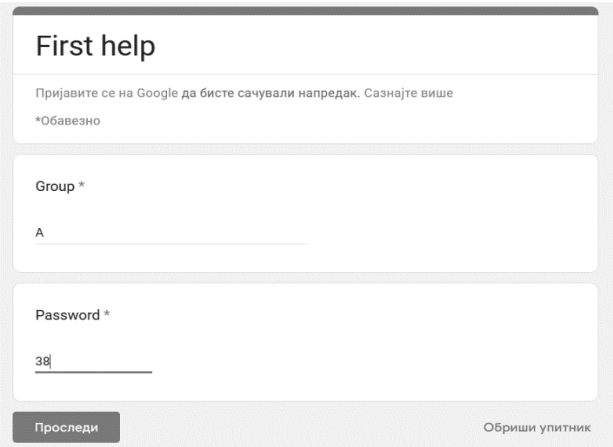


Figure 2. The application's user interface for creating passwords

After obtaining the correct password, students accessed a Google Form to input the password (see Figure 3a) and retrieve the assistance (see Figure 3b) provided in a Google Document (see Figure 4).

a)



b)

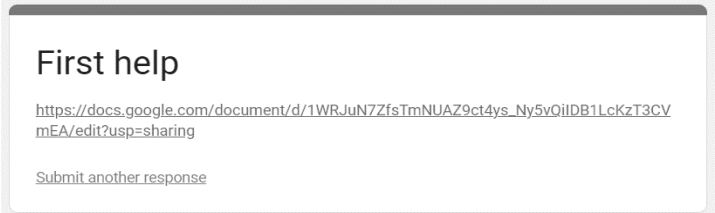


Figure 3. Google form for opening the first help a) Google form for imputing the password; b) If the password is correct, the link for the First help is provided

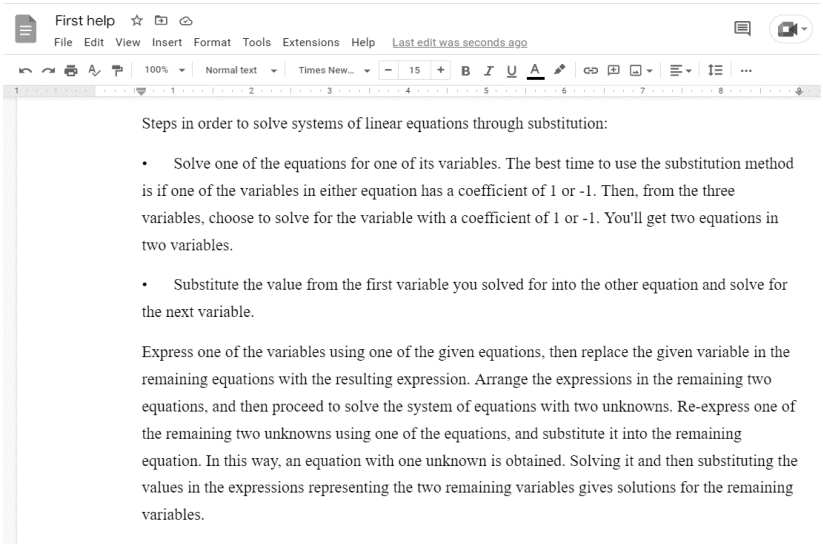


Figure 4. Protected Google document with first help

The password for "second help" was *53*, and again was known only to the teacher. Each of the students got one of the ordered pairs: *(2, 196), (3, 13), (1, 13), (4, 188), (6, 150), (5, 152)*

"Second help"

- Solve one of the equations for one of its variables. The best time to use the substitution method is if one of the variables in either equation has a coefficient of 1 or -1. Then, from the three variables, choose to solve for the variable with a coefficient of 1 or -1. You'll get two equations in two variables.
- Substitute the value from the first variable you solved for into the other equation and solve for the next variable.
- Repeat the same procedure with the two new equations.

$$-x - 2y + 14z = 8 \Rightarrow -x = 8 + 2y - 14z \Rightarrow x = 14z - 2y - 8$$

$$2x - 5y + 7z = 9$$

$$4x - 2y - 3z = 24$$

$$2(14z - 2y - 8) - 5y + 7z = 9$$

$$4(14z - 2y - 8) - 2y - 3z = 24$$

The "third help" password was *128*, known only to the teacher, and the students again receive one of the following ordered pairs: *(3, 211), (1, 117), (2, 64), (6, 189), (5, 214), (4, 106),*

"*Third help*"

- Solve one of the equations for one of its variables. The best time to use the substitution method is if one of the variables in either equation has a coefficient of 1 or -1. Then, from the three variables, choose to solve for the variable with a coefficient of 1 or -1. You'll get two equations in two variables.
- Substitute the value from the first variable you solved for into the other equation and solve for the next variable.
- Repeat the same procedure with the two new equations.
- Substitute the value from the two variables that you solved and plug it into the remaining equation and solve for the last remaining variable. This step should allow you to solve for a real number.
- After solving for the final variable, plug in the value of the most recent variable that you found into the answer of another equations with variables remaining. Note: Preferably, plug in the value to the most simplified equation.
- Therefore, you will have successfully found the answers to a system of linear equations in three variables.
- Note**.** It's always a good idea to check the solution back in the original equations just to be sure.

$$-x - 2y + 14z = 8 \Rightarrow -x = 8 + 2y - 14z \Rightarrow x = 14z - 2y - 8$$
$$2x - 5y + 7z = 9$$
$$4x - 2y - 3z = 24$$

$$2(14z - 2y - 8) - 5y + 7z = 9$$
$$4(14z - 2y - 8) - 2y - 3z = 24$$

$$35z - 9y = 25 \Rightarrow -9y = 25 - 35z \Rightarrow y = \frac{35z - 25}{9}$$
$$53z - 10y = 56$$

$$53z - 10\,\frac{35z - 25}{9} = 56$$

This method allowed pre-service teachers to independently decide if and how much help they needed. This had the potential to help students overcome their reluctance to actively participate in online group work. The teacher maintained a database linked to Google Forms to monitor which group members utilized the assistance, facilitating the grading process based on group participation.

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

The qualitative analysis of data collected from the six pre-service teachers provided valuable insights into their experiences and perceptions of using the cryptographic model for differentiated online group problem-solving.

Group Dynamics and Collaboration: All participants (6 of 6) reported an increase in collaborative efforts. The requirement for at least two-thirds of the group to agree before accessing assistance fostered a sense of responsibility and teamwork. Four participants indicated that discussions were more focused, with group members actively engaging in problem-solving rather than relying on individual efforts. However, two participants expressed frustration with delays caused by waiting for group consensus.

Utilization of Help Levels: The group opened two levels of assistance. Most participants (4 of 6) preferred to explore all possible problem-solving strategies independently before turning to assistance, while two preferred quicker access to group help. The availability of differentiated help was positively viewed as it promoted ownership of learning. On the other hand, one participant felt that the points reduction system added pressure, which somewhat hindered their willingness to use help early.

Perceived Effectiveness of the Software: The software for password retrieval was seen positively by most participants (5 of 6), who appreciated its simplicity and accessibility. However, two participants suggested adding features, such as immediate feedback on their decisions to use assistance. One participant also noted that while the system worked well, the process of entering individual key parts could be made more streamlined.

Learning Outcomes: All six participants successfully completed the mathematical task. Five participants felt more confident in their problem-solving abilities due to the collaborative structure and help system. However, one participant mentioned that they would have preferred more personalized guidance, as the group-based help did not fully address their specific learning needs.

Discussions

The research question in this study was how the integration of a cryptographic model for differentiated online group problem-solving influences collaboration, engagement, and learning outcomes among pre-service teachers. The results indicate that this model significantly contributes to increased collabora-

tion among participants, with the majority of pre-service teachers reporting greater engagement in collective problem-solving. The help system, which provides differentiated support, was generally positively evaluated. The implementation of the cryptographic model among pre-service teachers reveals several critical insights into collaborative problem-solving in online educational settings.

The requirement for group consensus before accessing assistance appears to promote accountability and peer support, aligning with Vygotsky's (1978) social constructivist theory, which emphasizes the importance of social interaction in learning processes. This finding is consistent with studies indicating that collaborative problem-solving enhances student engagement and learning outcomes (Tian and Zheng, 2024). However, the frustration expressed by some participants regarding delays suggests a need to balance collaborative requirements with individual pacing, echoing challenges noted in collaborative learning environments (Ying and Tiemann, 2024).

The tiered assistance approach provided by the cryptographic model aligns with differentiated instruction principles, allowing students to engage at their own levels while still benefiting from group support (Tomlinson, 2001). The success of the participants in completing the mathematical task suggests that such an approach may effectively address diverse learning needs in educational contexts. The preference for independent exploration before seeking help underscores the model's effectiveness in promoting learner autonomy. Nevertheless, the pressure induced by the points reduction system highlights the delicate balance required in designing motivational elements within educational tools, as extrinsic motivators can sometimes undermine intrinsic motivation (Baucal et al., 2023).

The positive reception of the software's simplicity and accessibility aligns with research emphasizing the importance of usability in educational tools, as technology can either facilitate or hinder collaborative efforts depending on its design (Nielsen, 1993). The suggestions for immediate feedback and streamlined processes reflect a broader demand for user-centered design in educational technology, which is crucial for maintaining engagement and effectiveness.

The successful completion of the mathematical task by all participants indicates the potential effectiveness of the cryptographic model in supporting collaborative problem-solving in mathematics (Felmer, 2023; Tian and Zheng, 2024; Ying and Tiemann, 2024). The increased confidence reported by most participants is a positive outcome; however, the desire for more personalized guidance points to the ongoing challenge of addressing individual learning needs within group settings. This finding resonates with the principles of differentiated instruction, which advocate for tailoring educational experiences to meet diverse student needs (Kurnila and Juniati, 2025).

Based on these findings, it can be concluded that the cryptographic model enhances group dynamics, responsibility, and problem-solving abilities.

Implications for research and practice

The cryptographic model for differentiated online group problem-solving presents several key implications for both research and educational practice.

Its structured assistance system promotes collaboration by encouraging group consensus and accountability, fostering a more interactive and cooperative learning environment. By requiring a majority agreement to access assistance, this approach reduces the need for constant teacher oversight, shifting responsibility to students and empowering them to manage their own learning (Baucal et al., 2023). In the future, this system could evolve to integrate more flexible, student-centered strategies, enabling even greater autonomy and deeper engagement in collaborative learning. It may also support the development of lifelong learning habits, where students continuously refine their skills in a cooperative and self-regulated environment.

The model is adaptable across various subjects and educational levels, making it highly versatile and relevant in diverse curricula. It also supports differentiated instruction by ensuring that students engage meaningfully with tasks before seeking help, potentially minimizing superficial learning. Furthermore, its flexibility allows for the accommodation of diverse learning styles and paces, fostering an environment where students can take ownership of their learning. This adaptability also enables educators to tailor their teaching approaches, enhancing the overall effectiveness of instruction in a wide range of educational contexts (Kurnila and Juniati, 2025).The cryptographic approach helps reduce academic dishonesty, such as plagiarism or over-reliance on external resources, by controlling access to step-by-step assistance. This system is particularly valuable in problem-solving disciplines like mathematics,

where gradual assistance can guide students without providing full solutions too early. By embedding cryptographic safeguards, the model promotes integrity in collaborative work and ensures that help is only unlocked when a consensus is reached. Additionally, it encourages students to engage with the material more deeply, promoting independent critical thinking and problem-solving skills. By ensuring that assistance is accessed in a controlled manner, the model fosters a more authentic learning experience and reinforces academic integrity in the learning process.

Incorporating artificial intelligence (AI) into this model could further enhance its effectiveness by providing adaptive support and more sophisticated monitoring of group dynamics. Likewise, integrating cryptography into AI-enhanced learning environments would add a vital layer of security and structure, especially in managing collaborative learning contexts. Cryptographic techniques could ensure that sensitive data-such as students' interactions, progress, and access to resources-are securely managed and only available under agreed-upon group conditions. This could help address growing concerns over data privacy in education, where clear policies are crucial (Mandić, 2023).

In modern education, teachers need to embrace AI as a tool that complements their expertise and enhances their ability to meet diverse student needs (Mandić, 2023; 2024). At the same time, careful planning and execution of strategies prioritizing student well-being, fairness, and effective pedagogy are essential for AI integration (Mandić et al., 2024; Milutinović and Mandić, 2022). Integrating cryptography into AI-driven learning systems could ensure secure, ethical access to assistance, upholding privacy and fairness while improving student engagement and accountability. This framework aligns with ethical concerns surrounding AI, providing a secure, transparent, and equitable model for modern education.

Conclusions

In conclusion, the implementation of the cryptographic model for differentiated online group problem-solving among six pre-service teachers has proven to be a successful and enriching experience. This method not only facilitated effective collaboration and engagement among participants but also positively influenced their learning outcomes. The findings suggest that integrating structured assistance systems into online education can enhance student motivation, accountability, and overall learning effectiveness.

In light of the ongoing challenges posed by the COVID-19 pandemic, the increasing demand for online learning, and the use of AI in education, it is crucial to establish robust organizational systems that allow students to choose when and under what circumstances they receive supportive information. Platforms like Moodle enable not only material sharing but also effective communication and project planning among group members. By implementing cryptographic techniques, group members can access appropriate resources only with the consent of the majority, ensuring that assistance is sought collaboratively. This approach fosters dialogue and exchange of ideas, making the learning process more interactive while simultaneously instilling a sense of shared responsibility for problem-solving.

Moreover, this model alleviates the instructor's burden, allowing them to focus on higher-order teaching tasks rather than micromanaging group dynamics and point deductions. It also minimizes subjectivity in assessing student contributions, fostering a fairer evaluation process. The adaptability of this method to various subjects and educational levels enhances its applicability and reduces the risk of academic dishonesty in group assignments.

This study presents a viable model for online collaborative learning across diverse educational contexts. Future research should focus on exploring the practical application of this model in mathematics education, examining students' attitudes, perceived advantages, and challenges, as well as their achievements. Additionally, investigating the model's efficacy across different subjects and contexts would further validate its potential in enhancing collaborative learning experiences.

While the method shows promise, potential limitations exist, such as students seeking external help through forums or private lessons, and technical issues like antivirus software misidentifying the program as a virus. Addressing these challenges will be essential for the effective implementation of this innovative approach in educational settings

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, M.V. and Đ. S.; methodology, M.V. and Đ. S.; investigation, M.V.; software, M.V. and Đ. S.; formal analysis, M.V.; writing—original draft preparation, M.V., Đ. S., and M.D.; writing—review and editing, M.V., Đ. S., and M.D. All authors have read and agreed to the published version of the manuscript.

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Behavioral Cultural Intelligence, Legal System, Cybersecurity and Cultural Heritage as Determinants of the Choice of Foreign Tourist Destinations

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Abstract: The development of information technologies and transport services has significantly facilitated the organization of business and tourist trips to countries worldwide. Consumers' decisions regarding which tourist destination to visit are determined by numerous factors. The research examine the effect of behavioral cultural intelligence, uncertainty avoidance, the legal system and safety, as well as cultural heritage on the choice of foreign tourist destinations. The empirical research was conducted using a survey method in the Republic of Serbia during 2024 on a sample of 388 respondents, whose responses were analyzed using the statistical software SmartPLS4. The results showed that uncertainty avoidance has a negative impact, while behavioral cultural intelligence, the legal system and safety, and cultural heritage have a positive impact on the choice of foreign tourist destinations, providing valuable information for marketers of multinational companies.

Keywords: *behavioral cultural intelligence, uncertainty avoidance, legal system and cybersecurity, cultural heritage, foreign tourist destinations.*

Introduction

The development of transportation infrastructure, communication channels, and the globalization process has led to an increase in travel to foreign tourist destinations (Bhardwaj, 2022). Various factors influence consumers' decisions when choosing an international tourist destination to visit. ***The subject and aim of this paper*** are to analyze the effects of behavioral cultural intelligence, uncertainty avoidance, the legal system and safety, and cultural heritage on the selection of foreign destinations. Behavioral cultural intelligence and uncertainty avoidance can be classified as ***push factors***, or internal motivators that drive an individual to visit a foreign tourist destination. On the other hand, the legal system and safety, along with cultural heritage, represent ***pull factors***, or external factors that attract consumers to a particular foreign tourist destination (Zdravković and Peković, 2021).

Behavioral cultural intelligence includes specific verbal (language) and non-verbal skills (gestures, body language) that help a person adapt when visiting a foreign country. Possessing cultural openness, cosmopolitan attitudes, perspectives, understanding, and knowledge of foreign languages greatly facilitates communication with the local population, making the stay abroad more comfortable (Zhang et al., 2021). ***Uncertainty avoidance*** is one of the dimensions of national cultures, reflecting the belief that it is necessary to avoid risky and unfamiliar situations and that everything should be regulated by certain norms, regulations, and procedures (Hofstede, 2001), Individuals with a high degree of uncertainty avoidance will primarily spend their vacations at familiar domestic tourist destinations, while those with a low

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degree of uncertainty avoidance seek new, interesting, and authentic experiences and typically spend their vacations at foreign tourist destinations (Shahriari et al., 2023).

Certain individuals prefer to travel only to safe tourist destinations, specifically to countries with a well-regulated ***legal system*** that take all necessary measures to prevent potential terrorist attacks, which recently have raised significant concerns among governments and caused fear among tourists (Liu et al., 2021; Vereb et al., 2018). In addition to physical safety, cybersecurity is becoming increasingly important in e-tourism, as tourists frequently use online platforms for bookings, payments, and communication. The lack of adequate cybersecurity measures can lead to the compromise of personal data and weaken tourists' trust in specific destinations. Therefore, countries that invest in the protection of digital infrastructure gain a competitive advantage in attracting tourists who value the safety of their data. (Florido-Benítez, 2024)

One of the most common challenges in e-tourism cybersecurity is the protection of personal and financial data processed during online bookings and payments. Website hacking, credit card data theft, and phishing attacks can cause significant harm to both individuals and the reputation of tourism platforms. Tourists increasingly seek platforms with advanced security protocols, such as two-factor authentication and data encryption, to ensure that their information remains secure. (Florido-Benítez, 2024)

An increasing number of tourists demand transparency from travel platforms regarding data processing. Companies that openly communicate the measures they take to protect personal and financial information gain greater trust from users. For example, the use of tools for real-time activity monitoring, as well as regular security reports, can significantly enhance a platform's reputation. Additionally, integrating technologies such as blockchain for transaction recording provides an added layer of security, which many tourists consider a decisive factor when choosing a booking platform (Masseno, 2018).

On the other hand, cybersecurity is also crucial for the preservation of critical infrastructure in tourism, such as systems for managing hotels, airlines, and transportation. Attacks on these systems can lead to massive operational disruptions, endangering both tourists and the local economy. Therefore, the adoption of state-of-the-art cybersecurity standards is becoming a vital factor in promoting destinations as reliable and safe. (Lykou et al., 2019)

Moreover, collaboration between the private sector and government agencies is becoming essential for establishing a secure cyber infrastructure. Governments that invest in training local cybersecurity experts and implementing new technological solutions can position themselves as leaders in the field of safe tourism. Public awareness campaigns emphasizing the importance of cybersecurity among tourists also play a key role in building trust. These initiatives, combined with strict regulatory frameworks, ensure long-term stability and attractiveness of tourist destinations (Bada and Nurse, 2019).

Additionally, some tourists choose only foreign tourist destinations recognized for their cultural identity, rich ***cultural heritage***, and legacy, as these individuals enjoy visiting foreign museums, operas, cultural monuments, and architectural landmarks of other countries (Genc and Gulertekin Genc, 2023; López-Guzmán et al., 2019)

Another goal of this paper is to determine if there are differences in the effect of behavioral cultural intelligence, uncertainty avoidance, legal system and safety, and cultural heritage on the selection of foreign destinations, based on the classification ***Generation X*** (between 1960 and 1980) and ***Generation Z*** (born after 1995). Young people generally have a greater desire and enthusiasm to visit foreign tourist destinations with rich cultural heritage and that offer opportunities for entertainment and enjoyment (e.g., activities such as student exchange), while older individuals typically prefer to spend their vacations in peaceful and safe tourist destinations (Zdravković and Peković, 2021).

After the introductory section of the paper, the literature review will define the research variables: *behavioral cultural intelligence, uncertainty avoidance, legal system and safety, cultural heritage, and the selection of foreign tourist destinations*. Their interrelationships will also be analyzed. This section will formulate research hypotheses, based on which the research model will be developed. The third section provides information on the conducted empirical research within the Republic of Serbia, presents the structure of the respondent sample, and outlines the statements that participants rated in the questionnaire. The fourth section covers the results obtained through the statistical software SmartPLS 4, while the conclusion will discuss the main implications derived from this study.

Literature review

Cultural intelligence encompasses a set of abilities, competencies, and skills that facilitate a person's adaptation and navigation in multicultural situations. The concept of cultural intelligence was introduced into academic literature by (Earley and Ang, 2003), who identified four basic components of cultural intelligence: *metacognitive, cognitive, motivational, and behavioral factors*. The metacognitive factor refers to an overall level of cultural knowledge, while the cognitive factor involves familiarity with political and social systems of other countries. The motivational factor represents an individual's desire to learn about foreign cultures, whereas the behavioral factor includes a set of skills that ease one's stay abroad (Zdravković and Peković, 2021). This study specifically examines the effect of the ***behavioral factor*** on the choice of foreign *tourist* destinations. Previous studies (Hu et al., 2021; Zhang et al., 2021) have found that a high level of behavioral cultural intelligence is a significant push factor and positively influences consumers' choices of foreign tourist destinations. Thus, the first hypothesis can be formulated as follows:

H_1: Behavioral cultural intelligence has a enable positive impact on consumers' choice to visit foreign destinations.

According to (Hofstede, 1980), there are four main dimensions that differentiate national cultures: *power* distance*, uncertainty avoidance, individualism vs. collectivism, and masculine vs. feminine values.* Power distance refers to the attitudes of a nation's members toward the distribution of power in society. A high power distance indicates acceptance of an unequal power distribution concentrated in the hands of a few, while a low power distance suggests that power is equally and evenly distributed. A high degree of uncertainty avoidance means that people dislike new and unfamiliar situations, whereas a low degree implies that people embrace innovative situations and challenges. Individualism implies weak interpersonal bonds within a culture and emphasizes independence, while collectivism is characteristic of societies that value family ties and connectedness. Masculine values emphasize material wealth, while feminine values prioritize friendly relations and social well-being (Hofstede, 2001). This study focuses on analyzing the impact of the cultural dimension of ***uncertainty avoidance*** (push factor) on the selection of foreign tourist destinations. A low *level* of uncertainty avoidance generally indicates innovative consumer behavior and a desire to visit foreign tourist destinations, while people with a high level of uncertainty avoidance tend to have an aversion toward foreign tourist destinations (Arieftiara et al., 2019; Zhu et al., 2023). According to data (Hofstede Insights, 2020), a high level of uncertainty avoidance is present in the Republic of Serbia (with an index value above 90 on Hofstede's scale of 1–100). Based on this assertion, the second hypothesis can be formulated as follows:

H_2: Uncertainty avoidance has a notable negative impact on the choice of foreign destinations.

When choosing a foreign tourist destination, a significant pull factor is the organization of the ***legal system and safety*** in that country. Tourists want to visit countries where legal regulations, procedures, and international law *are* respected, as well as those that take all necessary security and protection measures against terrorist attacks (Agarwal et al., 2021). Such threats cause great fear among tourists when considering certain destinations for vacations or when visiting foreign countries for music and film festivals, major sports events like the Olympic Games, or any event that attracts a large audience (Kılıçlar et al., 2018; Vereb et al., 2020). Previous studies (Agarwal et al., 2021; Tasci and Sönmez, 2019) indicate that a well-organized legal system ensures tourist safety and strengthens their desire to visit foreign tourist destinations, leading to the formulation of the third hypothesis:

H_3: The legal system and safety have a notable positive impact on the choice of foreign destinations.

Cultural heritage represents one of the most significant pull factors that encourages and motivates consumers to visit a particular foreign tourist destination (Mou and Quelhas Brito, 2024). Many destinations attract tourists with their magnificent architectural landmarks, cultural monuments, operas, rich history, numerous churches, *monasteries*, and so on (Le Hong and Hsu, 2024; Rozanis et al., 2024). By learning about the history and traditions of other countries, people broaden their perspectives, develop cultural intelligence and openness, and gain new knowledge. Cultural tourism is becoming increasingly important, as more and more tourists choose a destination based on the cultural heritage it possesses (Zaman and Aktan, 2021). Previous research (López-Guzmán et al., 2018a; López-Guzmán et al., 2018b) has found that a country's cultural heritage is one of the main determinants of tourists' decisions to visit that country. Based on this, the fourth

hypothesis can be formulated:

H_4: Cultural heritage has a notable positive impact on the choice of foreign destinations.

The secondary aim of this study is to determine whether there are differences in the impact of research variables on the selection of foreign destinations when is used as a criterion classification Generation X (people born between 1960 and 1980) and Generation Z (people born after 1995). Young people, such as students, often participate in exchange programs and travel to foreign countries where they complete their master's or doctoral studies. Older individuals with successful careers frequently travel abroad for business purposes, while those with considerable free time, like retirees, often travel to foreign *countries* for tourism. Previous studies (Agarwal et al., 2021; Vereb et al., 2020) have found that older individuals place great importance on feeling safe at foreign tourist destinations and prefer to avoid unfamiliar situations that may cause difficulties during their stay. On the other hand, previous research (Pandey and Charoensukmongkol, 2019; Rambocas and Mahabir, 2021) indicates that young people have developed cultural intelligence and openness to other countries and are interested in exploring the cultural heritage and traditions of other nations. Based on these statements, the following research hypotheses can be formulated:

H_{5a}: The effect of behavioral cultural intelligence on the selection of foreign destinations is more pronounced among consumers belonging to Generation Z.

H_{5b}: The impact of uncertainty avoidance on the selection of foreign destinations is more pronounced among consumers belonging to Generation X.

H_{5c}: The effect of the legal system and safety on the selection of foreign destinations is more pronounced among consumers belonging to Generation X.

H_{5d}: The effect of cultural heritage on the selection of foreign destinations is more pronounced among consumers belonging to Generation Z.

Based on the formulated subject and objectives of the research, as well as the hypotheses, a research model has been designed, as presented in Figure 1.

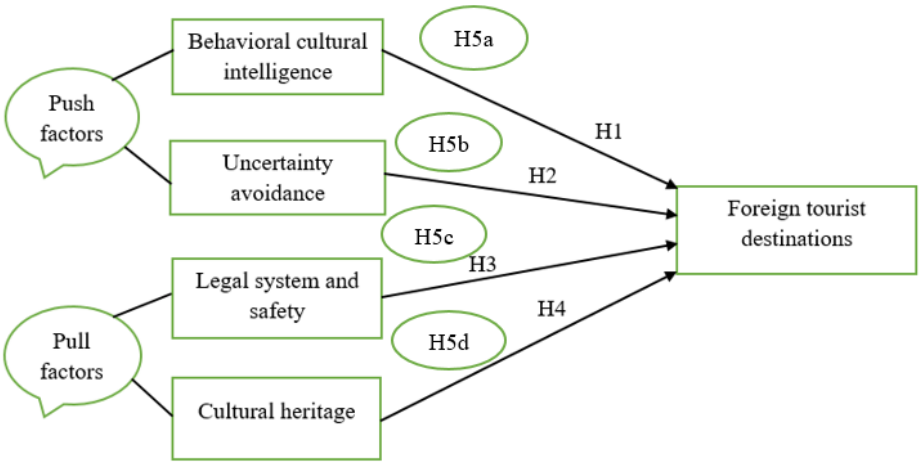

Figure 1. Research model

Materials and Methods

The empirical research was conducted on the territory of the Republic of Serbia during 2024, both in person and electronically (survey). The total number of respondents is 388.

Table 1. *Demographic characteristic*

		Number	Percentage
Gender	Female	187	48.2%
	Male	201	51.8%
	Total	**388**	**100%**
Age	Generation X	114	29.4%
	Generation Y	127	32.8%
	Generation Z	147	37.8%
	Total	**388**	**100%**
Education	Primary education	11	2.8%
	High school	174	44.9%
	Faculty	203	52.3%
	Total	**388**	**100%**

Source: Authors

In the total sample, there are 201 male and 187 female respondents. Regarding the age category, the sample includes a relatively balanced number of respondents from the generational cohorts X, Y, and Z. In terms of education, the majority of respondents have completed a faculty 203 (52.3%).

The respondents rated statements related to the research variables using a ***Likert scale*** ranging from 1 to 7. The statements were sourced from relevant literature, with an overview provided in Table 2.

Table 2. *Statements from the questionnaire*

Research variables	Statements	Source, adapted from:
Behavioral cultural intelligence	I possess verbal skills (accent, tone of voice) that make my stay abroad easier. I possess non-verbal skills (body language) that are important in multicultural situations. Cultural openness and knowledge of a foreign language make staying abroad more enjoyable.	Earley and Ang (2003)
Uncertainty avoidance	Traveling to certain tourist destinations carries a certain level of risk. I do not like traveling to distant and less-explored tourist destinations. I do not like interacting with the local population when traveling abroad.	Hofstede (2001)
Legal system and safety	It is important to me that the country I visit for tourism has an organized legal system. It is very important that the country I wish to visit takes all necessary measures to prevent terrorist attacks. It is important for me to feel safe and secure during my stay abroad.	Liu et al. (2021); Tasci and Sonmezb (2019); Vereb et al. (2018)
Cultural heritage	I enjoy visiting museums and operas during my stay abroad. Knowledge of the history of other countries and visiting cultural monuments are very valuable to me. When choosing a foreign tourist destination I wish to visit, I consider whether it is recognized for its cultural heritage.	Rahman et al. (2021)
Foreign tourist destinations	I usually spend my annual vacations at foreign tourist destinations. I recommend to my friends that they visit some foreign tourist destinations. I recommend to my family members that they frequently visit foreign tourist destinations.	Zdravković and Peković (2021)

Source: Authors

In the next section, the results of the empirical research will be presented, based on which decisions will be made regarding the confirmation of the research hypotheses.

Research and Discussion

To analyze the interrelationships among the statements used to measure the research variables, a ***reliability analysis*** was applied (Table 3).

Table 3. *Reliability analysis*

Research variables	Cronbach's alpha	Composite reliability (rho_a)
Behavioral cultural intelligence	0.824	0.844
Uncertainty avoidance	0.887	0.866
Legal system and safety	0.867	0.811
Cultural heritage	0.855	0.829
Foreign tourist destinations	0.899	0.871

Source: Authors' calculation using SmartPLS 4 software

Based on the results, we conclude that all values indicators ***Cronbach's alpha*** and ***Composite reliability (rho_a)*** are greater than the required statistical threshold of 0.70, indicating that the variables are measured using adequate statements.

The SEM model was implemented to examine the effects of behavioral cultural intelligence, uncertainty avoidance, legal system and safety, and cultural heritage on the selection of foreign destinations (Table 4).

Table 4. Structural Equation Model (SEM)

Hypothesis	Original sample (O)	Standard deviation (STDEV)	T statistics (IO/STDEVI)	P values
Behavioral cultural intelligence Foreign tourist destinations	0.387	0.037	5.284	0.000**
Uncertainty avoidance Foreign tourist destinations	-0.367	0.052	5.127	0.000**
Legal system and safety Foreign tourist destinations	0.448	0.021	7.347	0.000**
Cultural heritage Foreign tourist destinations	0.411	0.036	7.118	0.000**

Level of statistical significance: **0.01; R square=0.578

Source: Authors' calculation using SmartPLS 4 software

The ***coefficient of determination*** (R square) is 0.578, which means that 57.8% of the variability in the choice of foreign tourist destinations is explained by the given model. Uncertainty avoidance **(coefficient= -0.367, p values=0.000)** has a significant negative statistical impact on the choice of foreign tourist destinations, while behavioral cultural intelligence **(coefficient= 0.387, p values=0.000)**, legal system and safety **(coefficient= 0.448, p values=0.000)**, and cultural heritage **(coefficient= 0.441, p values=0.000)** have notable impact on the selection of foreign tourist destinations. Research hypotheses **H1, H2, H3, and H4 have been confirmed**.

In the study, ***Bootstrap Multigroup Analysis (MGA)*** was applied to determine whether there are differences in the effect of behavioral cultural intelligence, uncertainty avoidance, legal system and safety, and cultural heritage on the selection of foreign destinations (Table 5) from the perspective of the demographic characteristic of age (Generation X and Z).

Table 5. *Bootstrap Multigroup Analysis (MGA) - demographic characteristic age*

Relations	Generation X	Generation Z	Difference (absolute)	P values
Behavioral cultural intelligence → Foreign tourist destinations	0.287	0.425	0.138	0.005**
Uncertainty avoidance → Foreign tourist destinations	-0.457	-0.298	0.159	0.000**
Legal system and safety → Foreign tourist destinations	0.512	0.398	0.114	0.008**
Cultural heritage → Foreign tourist destinations	0.311	0.469	0.158	0.000**

Level of statistical significance: **0.01

Source: Authors' calculation using SmartPLS 4 software

The results show that the impact of uncertainty avoidance **(difference 0.159, p values 0.000)** and the legal system and safety **(difference 0.114, p values 0.008)** on the selection of foreign destinations is more pronounced among respondents from Generation X, while the effect of behavioral cultural intelligence **(difference 0.138, p values 0.005)** and cultural heritage (**0.158, p values 0.000)** on the selection of foreign destinations is stronger among respondents from Generation Z.

Based on this, the **hypotheses** of the **observed research H5a, H5b, H5c, H5d** were fully **confirmed**.

Conclusions

The research was conducted to examine the effects of behavioral cultural intelligence, uncertainty avoidance, legal system and Cybersecurity protecting system, and cultural heritage on the selection of foreign destinations.

The results of the empirical study, conducted in the territory of the Republic of Serbia as a unique territorial entity, showed that uncertainty avoidance has a negative impact, while behavioral cultural intelligence, the legal system and safety, and cultural heritage have a positive impact on the choice of foreign tourist destintions.

The effect of uncertainty avoidance, as well as the legal system and safety on the selection of foreign destinations, is more pronounced among consumer from Generation X, and the impact of behavioral cultural intelligence and cultural heritage on the selection of foreign destinations is stronger among consumers from Generation Z.

Theoretical contribution reflect an expansion of scientific knowledge on the effect of these variables on the choice of foreign destinations.

Practical implications involve providing information to marketers that can be notable in formulating marketing strategy.

A ***limitation of the research*** is that it was conducted in only one country, suggesting that ***future studies*** could focus on cross-cultural research and enhance the research model with additional significant determinants of foreign tourist destination choice, such as ethnocentrism, cosmopolitanism, xenocentrism, cultural openness, and similar factors.

It is also possible to analyze the effect of other factors of cultural intelligence and other dimensions of national cultures on the choice of foreign tourist destinations.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization: I.T. and Ž.S., Formal Analysis: Ž.S., D.D. and S.Z., Investigation: I.T. and G.D, Methodology: I.T., Ž.S. and S.Z., Writing – original draft: I.T., M.I. and S.Z., Writing – review & editing: Ž.S., G.D. and S.Z. All authors have read and agreed to the published version of the manuscript.

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Examining Multimodal Literacy Skills Among EMI Teachers in Kazakhstan

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Abstract: The integration of English as a Medium of Instruction (EMI) in Kazakhstani universities necessitates effective multimodal communication in teaching. However, limited research has explored EMI instructors' multimodal literacy—their ability to utilize verbal, visual, and textual elements to enhance instruction. This study investigates the relationship between EMI instructors' ability to express and interpret multimodal content and their preference for multimodal communication in teaching at a Kazakhstani university. A quantitative research design was employed, utilizing a validated survey instrument to assess 120 teachers' multimodal literacy levels in one Kazakhstani university. The collected data underwent reliability analysis, descriptive statistics, and Pearson correlation analysis to examine the relationships among multimodal expression, interpretation, and preference. The results indicate that while teachers acknowledge the value of multimodal approaches, they encounter significant challenges in integrating them effectively. Variations in internal consistency suggest that certain aspects of multimodal communication remain difficult to master. Additionally, the findings reveal that teachers who demonstrate strong multimodal interpretation skills do not necessarily prefer using such methods in teaching. These findings suggest a gap between EMI instructors' multimodal literacy and their instructional preferences, highlighting the need for targeted faculty development programs that enhance multimodal teaching strategies.

Keywords: *English as a medium of instruction, Multimodal Literacy Scale, higher education, multimodal training, university teachers.*

Introduction

In recent years, English as a Medium of Instruction (EMI) has gained significant traction in higher education institutions worldwide, particularly in non-Anglophone countries (Dearden, 2015). Kazakhstan, as part of its educational reform initiatives, has increasingly adopted EMI to enhance global competitiveness and academic integration (Kaiypova and Kim, 2024). Since the adoption of the EMI format for delivering courses in non-linguistic majors, Kazakhstani higher education institutions have begun formulating relevant policies, creating and introducing numerous English-taught academic programs, and developing diverse methodologies to ensure effective implementation (Tulepova et al., 2024:434). However, ensuring effective communication and knowledge transfer in multilingual and multicultural classrooms still requires educators to develop multimodal literacy skills.

Multimodal literacy refers to the ability to interpret, express, and engage with meaning through multiple modes of communication, such as visual, auditory, gestural, and textual elements (Walsh, 2010). Given the diverse nature of modern classrooms and the increasing reliance on digital technologies in teaching and learning, EMI teachers must be adept at utilizing multimodal resources to enhance student engagement and comprehension (Morell, 2018). According to Custodio-Espinar and López-Hernández, "multimodality can be useful in EMI contexts to measure and evaluate different ways of meaning-making produced by students" (2023, p.7). Despite its importance, there is limited empirical research on EMI teachers' multimodal literacy skills, particularly in Kazakhstan. Understanding their competencies and

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preferences regarding multimodal communication is crucial for addressing potential challenges, for mastering "behavioral strategies that form a concrete benefit related to good organization, control, and responsibility of participants in the educational process" (Tasevska and Ivanov, 2022:47) and for informing professional development programs (Sutrisno et al., 2023). Thus, this study seeks to bridge this gap by examining the multimodal literacy skills of EMI teachers at a private university in Kazakhstan. Specifically, it investigates teachers' ability to express themselves using multimodal structures, their interpretation of multimodal content, and their preferences for multimodal communication in the classroom using a validated survey instrument developed by Bulut et al. (2015). Therefore, the research question was formulated as follows: ***How do EMI teachers in Kazakhstan demonstrate multimodal literacy skills, and what is the relationship between their ability to express and interpret multimodal content and their preference for multimodal communication in the classroom***

Theoretical framework

This study adopts Multimodal Social Semiotics (Kress, 2009) as its theoretical lens to explore EMI teachers' multimodal literacy skills. Multimodal Social Semiotics posits that meaning-making occurs through multiple modes - such as speech, writing, images, and gestures - each with distinct affordances that contribute to communication and knowledge construction. This presupposes a "meaning-centered management of the educational environment that provides conditions for maximum personalization of the learning process by transforming the traditional process of transmitting educational communication into an organic and authentic dialogue" (Dermendjieva et al, 2020:77). In the context of EMI, where linguistic barriers may exist, effective teaching relies not only on verbal proficiency but also on the strategic integration of multimodal resources to facilitate understanding (Morell, 2020). This may be due to the fact that since content specialists are not always fully proficient in the language, they often rely on a combination of written text, visual aids, body language, and speech to convey and elicit meaning (Morell, 2018).

Within EMI classrooms, multimodal literacy enables teachers to scaffold content, clarify complex concepts, and engage students through diverse semiotic modes (Tai and Wei, 2024). This study focuses on three key dimensions of multimodal literacy: expression, referring to teachers' ability to convey meaning using multimodal strategies; interpretation, involving their ability to decode and analyze multimodal content; and preference, reflecting their inclination towards using multimodal communication in instructional settings, defined by Bulut et al. (2015). By applying Multimodal Literacy Scale, this research aims to uncover how EMI teachers navigate and utilize multimodal resources to enhance teaching effectiveness in a multilingual academic environment.

Materials and Methods

This study employed a quantitative research design employing a validated survey instrument designed by Bulut, Ulu and Kan (2015). Data collection was conducted via an online Google Forms survey platform. Participants completed the questionnaire anonymously. Data were screened for missing responses and outliers before proceeding to analysis via SPSS version 30.

The survey was conducted among 120 EMI teachers at one private Kazakhstani university. The respondents were recruited using a convenience sampling approach. Participants provided informed consent before completing the questionnaire. The gender distribution of the participants was 75% female (n = 90) and 25% male (n = 30). The participants' ages ranged from 21 to 35, with the largest group being 22-year-olds (70.9%). A smaller proportion of respondents were aged between 23 - 35, each making up between 4.2% and 8.3% of the total sample. Regarding teaching experience, the majority (58.3%) had been teaching for about a year or less, while 25% had between two and five years of experience. The remaining 16.7% reported having between six and ten years of teaching experience. These demographics suggest that the sample primarily consists of young and relatively inexperienced EMI teachers, which may have implications for their familiarity with multimodal literacy practices and the challenges they face in EMI instruction.

Results

This section presents the findings of the study, focusing on the reliability of the multimodal literacy scale, descriptive statistics of teachers' responses, and the relationships among the three multimodal literacy factors. First, the internal consistency of the scale was assessed using Cronbach's alpha coefficients, revealing varying levels of reliability across the three subscales. Next, descriptive statistics illustrate teachers' levels of agreement with statements related to expressing themselves using multimodal structures, interpreting multimodal content, and their preference for multimodal communication. Finally, Pearson correlation analysis was conducted to explore relationships between these dimensions, shedding light on how teachers' ability to express and interpret multimodal content relates to their preferences for using such methods in the classroom.

Table 1. Reliability results

Factors	Number of items	Cronbach's alpha coefficient values
Expressing Oneself Using Multimodal Structure	5	.648
Interpretation of the Contents Presented in Multimodal Structure	7	.731
Preferring Multimodal Structure	5	.815

In Table 1 above, the reliability of the scale used to measure multimodal literacy was assessed using Cronbach's alpha coefficients. The internal consistency of the three subscales varied, with "Preferring Multimodal Structure" showing the highest reliability (α = 0.815), indicating strong internal consistency among the five items measuring teachers' preferences for multimodal content. The "Interpretation of the Contents Presented in Multimodal Structure" subscale demonstrated acceptable reliability (α = 0.731), suggesting that the seven items in this factor are relatively consistent in measuring how well teachers interpret multimodal content. However, the "Expressing Oneself Using Multimodal Structure" subscale had a lower reliability score (α = 0.648), which suggests that the five items in this factor may not be fully cohesive or may require revision to enhance their consistency. Nevertheless, following Hair et al. (2009) on the development of new scales, we also kept the construct despite its' Cronbach's (1951) alpha of 0.648.

The descriptive statistics presented in Table 2 below indicate varying levels of agreement across the three categories. In the Expressing Oneself Using Multimodal Structure category, teachers generally showed moderate agreement, with mean scores ranging from 3.46 to 3.63, suggesting that they somewhat integrate visuals, music, and interactive elements into their presentations and writing. The Interpretation of the Contents Presented in the Multimodal Structure category displayed a similar trend, with most items scoring between 3.04 and 4.04. Notably, participants reported the highest agreement with recognizing how visual, auditory, and written elements influence individuals (M = 4.04, SD = 0.679) and using body language effectively (M = 3.96, SD = 0.679), while their ability to assess media content credibility scored the lowest (M = 3.04, SD = 0.938). In contrast, the Preferring Multimodal Structure category showed overall disagreement, as all mean scores were below 3.00. The lowest agreement was with the statement that multimodal elements lead to laziness (M = 2.21, SD = 1.044) and that multimodal communication is boring (M = 2.00, SD = 1.045), indicating that teachers generally do not find multimodal elements disengaging. However, a relatively higher score for being distracted in electronic multimodal environments (M = 2.92, SD = 1.157) suggests that some teachers may struggle with digital multimodal formats. Overall, the results imply that while EMI teachers recognise the value of multimodal communication and incorporate it into their teaching, they may still face challenges in fully embracing and effectively evaluating multimodal content.

Table 2. Descriptive statistics

Category	Items*	Mean	Standard Deviation
Expressing Oneself Using Multimodal Structure	I organize my thoughts systematically in my presentations thanks to various visual elements (such as tables and graphics).	3.58	1.081
	I prepare an interactive presentation making use of music, visuals, and animations	3.50	1.004
	Using various elements (such as music and images) in my presentations makes it easier to make my point.	3.46	1.229
	I use visuals such as graphics, tables, pictures, and photographs in my writings.	3.63	.908
	I express myself more explicitly in environments in which writing, sound, and images exist together	3.54	1.044
Interpretation of the Contents Presented in Multimodal Structure	I relate various visual and verbal information on various media tools to each other.	3.50	.820
	I interpret the information that I gather from numerous resources	3.42	1.001
	I can decide whether or not content presented on various media (newspaper, TV, social media, etc.) is true	3.04	.938
	I relate the information to which I have access using visual and auditory elements.	3.29	.844
	I pay attention to the body language of the individuals I am listening to	3.67	.947
	I use body language that is in harmony with the words I choose when speaking.	3.96	.679
	I can realize how visual, auditory, and written elements influence individuals.	4.04	.679
Preferring Multimodal Structure	I get bored in communication in which written, auditory, and visual elements are used together	2.00	1.045
	I get distracted in electronic environments in which visual, auditory, and written elements are used together.	2.92	1.157
	The use of visual, auditory, and written elements together leads to laziness of the mind.	2.21	1.044
	I do not like trying to interpret images, sounds, graphics, and writings simultaneously	2.50	1.195
	I only believe in the power of verbal expression when sharing my thoughts.	2.71	1.141

**Multimodal Literacy Scale items designed by Bulut et al. (2015)*

Further, in Table 3 below, we attempted to calculate the Pearson correlation in order to examine relationships between the three multimodal literacy factors. A moderate positive correlation was found between "Interpretation of the Contents Presented in Multimodal Structure" and "Expressing Oneself Using Multimodal Structure" (r = 0.439, p < 0.001). This suggests that teachers who are skilled at interpreting multimodal content are also more likely to express themselves effectively using multimodal formats. The strong statistical significance of this relationship (p < 0.001) indicates that this is a meaningful connection and not a random occurrence.

On the other hand, a weak negative correlation was found between "Expressing Oneself Using Multimodal Structure" and "Preferring Multimodal Structure" (r = -0.234). This suggests that teachers who are proficient in using multimodal approaches to express themselves may not necessarily prefer multimodal teaching strategies. Although the correlation is not strong, it indicates that teachers' ability to express ideas multimodally does not always align with their preference for using such methods in the classroom.

Similarly, a weak but statistically significant negative correlation was observed between "Interpretation of the Contents Presented in Multimodal Structure" and "Preferring Multimodal Structure" (r = -0.197, p = 0.031). This implies that teachers who are good at understanding multimodal content may not always prefer to use multimodal teaching methods. The statistical significance (p = 0.031) suggests that while the effect size is small, there is still a meaningful relationship worth exploring further.

Table 3. Pearson correlation analysis results

Pearson correlation	Expressing Oneself Using Multimodal Structure	Preferring Multimodal Structure
Preferring Multimodal Structure	-0.234478759326225	
Sig.(2-tailed)		
Interpretation of the Contents Presented in Multimodal Structure	0.43881599930589	-0.197132062504617
Sig.(2-tailed)	5.3489E-7	0.030920485150535

Discussion

The findings of this study highlight the crucial role of multimodal literacy in EMI instruction and the varying degrees to which teachers employ multimodal strategies in their teaching. The results indicate that EMI teachers in Kazakhstan demonstrate moderate competency in expressing themselves through multimodal structures and interpreting multimodal content. However, their preference for multimodal communication in the classroom remains relatively low, which may suggest limited pedagogical training in utilizing multimodal approaches effectively. These findings align with Morell (2018), who emphasized that while multimodal literacy is essential in EMI settings, teachers often lack the necessary skills and confidence to integrate various semiotic resources optimally.

Notably, our study found that while teachers acknowledge the importance of multimodal communication, they do not overwhelmingly prefer its use. This finding is consistent with Sutrisno et al. (2023), who argued that despite recognizing the benefits of multimodal literacy, EMI educators may be constrained by traditional teaching norms, limited institutional support, and a lack of formal training in multimodal pedagogy. Moreover, the lowest agreement scores were observed in statements related to evaluating media credibility, which suggests a need for enhanced critical multimodal literacy skills—an aspect also underscored by Walsh (2010).

These results have significant implications for EMI implementation in Kazakhstan. Given that the majority of respondents were young and relatively inexperienced, it is possible that their limited teaching experience may contribute to their underutilization of multimodal strategies. Similar to the findings by Morell (2020), our study underscores the necessity of equipping EMI teachers with structured training that fosters multimodal literacy development. Professional development programs should incorporate hands-on training in designing and implementing multimodal instructional strategies to enhance both comprehension and engagement in multilingual classrooms.

Conclusions

In conclusion, this study contributes to the growing body of research on multimodal literacy in EMI by providing empirical evidence from the Kazakhstani context. While EMI teachers demonstrate moderate competence in multimodal literacy, their limited preference for multimodal communication and challenges in digital environments suggest that further pedagogical training is necessary. Future research should explore the impact of targeted multimodal literacy interventions on EMI teaching effectiveness and investigate how institutional policies can support multimodal integration in higher education.

Additionally, we believe that the findings underscore the need for systematic faculty development initiatives that equip instructors with practical strategies for integrating multimodal resources into their teaching. Universities should consider implementing structured training programs that focus on enhancing both theoretical knowledge and hands-on application of multimodal techniques. Furthermore, given the observed discrepancies between instructors' multimodal interpretation skills and their teaching preferences, future studies should examine the underlying factors influencing teachers' reluctance to adopt multimodal strategies. This study provides valuable insights for policymakers, educators, and researchers interested in advancing EMI pedagogy through multimodal approaches. Addressing the identified challenges can contribute to the development of more inclusive and effective teaching strategies in multilingual higher education contexts.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

G.D.: conceptualization, revision, supervision, writing – review and editing; B.M: methodology, writing - original draft preparation, data analysis; T.S.: conceptualization, data collection, writing – review and editing; D.G.: writing – review and editing, supervision.

All authors have read and agreed to the published version of the manuscript.

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Academic Writing: Origins and Impact of Eloquence

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Abstract: The article deals with the unsettled question whether academic scientific writing can be eloquent and possess some expressive characteristics and what impact it has on the reader. Historically the evolution of classical science to post-non-classical one was marked with substantial changes in the stylistics of scientific genres. Post-non-classical science is characterized by profoundly new conceptual notions, interpenetration of different forms of discourse, and the use of expressive linguistic means and emotional components in research papers. The current paper shows that notwithstanding the apparent antinomy, the formal and expressive functions of academic writing can effectively "coexist" in modern science. The objective of the present paper is to identify socio-historical grounds for tolerance to emotional representation of academic knowledge, to describe the changes in post-non-classical science, which made emotiveness possible in academic writing, to reveal the ways of communicating emotiveness in academic discourse. The main methods of this research include textual and stylistic analysis of academic articles and their titles, selected from scientific journals indexed in authoritative databases and materials of British National Corpus. It was revealed that the scope of expressive vocabulary in academic writing depends on the genre of scientific prose. The linguistic expressive means used by the representatives of both humanities and natural sciences and technology include: metaphor, metonymy, epithets, intensifying adverbs, quantifiers, the use of precedent texts, assertion of the author's style and gender identity.

Keywords: *expressiveness, emotions, genre of scientific prose, scientific article, linguistic means, scientism, language functions..*

Introduction

Today, most research is conducted within the anthropocentric paradigm, i.e. taking into account human factor. Linguistic creative activity aims at transmitting not only objective and formal-logical data, but also subjective information enriched with evaluative judgments, intuitive and emotional insights. Such information is undoubtedly richer and more versatile than purely irrational statistics. It has been established that language, along with the informative function, performs an emotional-expressive function designed not only to communicate information, but also to express an attitude to what is said, which is one of the most productive ways to influence the reader or interlocutor. Many linguistic studies of the previous

40-50 years have been devoted to identifying and describing the connections between the informative and communicative functions of language, their linguistic representations and cognitive aspects (Diller, 1992; Gallois, 1993; Jacobsen, 1979; Johnson-Laird et al., 1989; Ortony et al., 1988; The Language of Emotions, 1997; Wierzbizcka, 1999).

Emotionality of speech is almost always aims at the most effective communication and achieved by means of text intensification. Speaking about intensifiers, it should be noted that the expressiveness of the word can be realized only in human speech, it is born in a dialogue with the outside world, accompanied by certain goals, experience, intentions and speaker's mood, that is, the word in a broad sense is subjective.

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The emotiveness of language has been studied by scientists most intensively since the end of the 19th century. The founder of such studies is Ferdinand de Saussure's student, Charles Bally, one of the outstanding representatives of the Geneva Linguistic School. There are many reasons for research of the language and speech emotiveness. One of them is that linguistic representations of emotions can serve as a key to their decoding, since human emotions are not always visually expressed. This is especially true for the texts where the reader does not directly observe the author's behavior, but can recognize the attitude through language. In this case, language decodes the emotional sphere of a person.

Naturally, different genres imply different degrees of emotiveness: from strictly scientific presentations of data to lyrical genres, odes and epigrams. Such modern genres as advertising, political or sports reports, debates, etc. cannot be imagined without emotive components, since their absence can lead to the loss of the very characteristics of these genres and, in general, can result in communicative failure.

Academic writing has traditionally been regarded as a domain characterized by objectivity, rationality, and distance. The prevailing belief has often been that emotions have no place in academia, where logical reasoning and empirical evidence reign supreme. However, recent discussions in educational psychology, composition studies, and rhetorical theory have begun to challenge this paradigm, suggesting that emotions can play a significant role in the process and product of academic writing.

Speaking about scientific discourse in general and academic writing in particular, today we can state the growing scientific interest in the study of eloquence and expressiveness of these genres due to a number of reasons, which we will discuss below. Today we are witnessing the fact that lexical, syntactic and other language structures, tradition-ally characteristic of literary and colloquial genres, are penetrating into the genres of scientific prose. This process is characterized as " 'Democratic Turn' in Science Dissemination" (Guinda, 2022). Such changes arouse from the question: what is more important – science for the sake of science or science for man? The first part is obviously important, and the realization of the second one has become possible only recently, with the emergence of new communication channels, with the spread of popular science content, motivating non-scientists to learn something new, which should be conveyed in an understandable language.

Modern trends in the development of science are determined by such processes as globalization, internalization, convergence of ethnic interests, intersection and interpenetration of scientific and consumer cultures. As a result, the linguistic design of scientific knowledge also undergoes changes, since it is a registrar and translator of these processes. In this respect, academic writing is characterized by blurred boundaries, the penetration of elements that were previously alien to it. V.A. Maslova notes diffuseness of the above characteristics, emphasizing that: "Diffusion can be considered a tendency of the entire modern culture, and not just science" (Maslova, 2021, p. 9).

In regard to scientific communication, there is an opinion (Kelly et al., 2016; Mur-Dueñas et al., 2022) that today's changes result in the development of "parascientific communication" which is not filtered by strict rules of formal scientific representation of knowledge. For example, speaking about visual abstracts to scientific papers, Guinda (2022) points out their "promotional" nature as well as "summarizing" one. Such abstracts combine numerous functions and characteristics, which has become possible only with the spread of online scientific communication. The scientists call such kind of abstract as hybrid as they "merge creation and mimesis, the verbal and the visual, naturalistic and symbolic representations, and borrow elements from a variety of discourses, such as marketing and advertising, fiction literature, the graphic novel and the comic book, cartooning, photography and film." (Guinda, 2022).

Thus, the relevance of this paper is determined by the need to identify the causes of changes in modern scientific discourse and the formation of polydiscursive tendencies in it, to consider the possibility of eloquence and the use of expressive constructs in academic writing and their influence on the addressee, as well as to determine the influence of these processes on the ethos of science with its absolute, in the Cartesian sense, nature.

Materials and Methods

The main methods of this research include textual and stylistic analysis of linguistic means. The materials include academic articles, the corpus of their titles, selected from scientific journals indexed in authoritative databases and materials of British National Corpus.

Results and Discussions

Emotions in Academic Writing: Problems and Discussions

Everything in the world is changing, much in language is changing, and academic discourse is not an exception. It has evolved since first scientific publications in the second half of the 17th century and is conventionally described as "clear evidence in writing that the writer(s) have been persistent, open-minded, and disciplined in study"; that classifies "reason over emotion or sensual perception"; and that implicates a reader who is "coolly rational, reading for information, and intending to formulate a reasoned response" (Thaiss and Zawacki, 2022, pp. 5-7).

The limited scope of the current article and the objectives of the study do not imply conducting a detailed analysis of the stages of science development and its main ideals. We will deal with the changes in the scientific style associated with the transition from the classical to the post-non-classical paradigm of scientific research. Except terminology, academic writing style was not a subject of linguistic research until the middle of the 20th century. The emergence of a specific genre – an academic research article - dates back to the second half of the 17th century. Before that the works by G. Galileo and I. Newton had referred to "scientific law" which was supposed to be free from all manifestations of mythology and anthropologism and the main objective of science was the "discovery of the law". This trend was continued by all subsequent scientists who pursued their scientific goals presenting the results of their research in a concise and accurate way: value-neutral, avoiding emotional interpretations, since such would contradict the formal abstract-logical interpretation of scientific discoveries.

In 1662, intellectualists from Oxford and London cooperated and founded a chartered organization "The Royal Society of London for Improving Natural Knowledge" with the motto "Nothing in words" (Latin: Nullius in verba), implying that science is to be based on strict data, experiment and calculations. Eloquence in the language of science was prohibited, since "it is contrary to reason and abets passion" (Barbalet, 2004, p. 248). It was apparently believed that passionate or emotional language could belittle science. Only a detailed, reliable, statistical, impartial description of scientific achievements was welcomed. However, a lot of scientists actually would not have succeeded in their research if they had not experienced violent emotions while working.

The idea of complete objectivity in academic writing has been criticized for oversimplifying the complex human experience of knowledge perception and production. Emotions are an integral part of all human activities, influencing how we reflect, categorize, and interact. Academic writers often find their research interests in personal experiences or passions which enrich their narratives, making their arguments more compelling. For instance, W. Harvey, upon the opening of systole and diastole, spoke of the experienced emotional turmoil caused by confusion (Harvey, 2022). In his research great Albert Einstein relied not only on objective statistics but also on his intuition and imagination: "Einstein was not led to his theories of special and general relativity through attention to data alone, as if following some experimental breadcrumbs. His theories were the offspring of his imagination as much as anything else" (Ellerton and Brown, 2018). According to M. Gross, "human emotions are not just fuzzy feelings but 'real' in an objective scientific sense, inasmuch as they produce measurable signals in reproducible experiments" (Gross, 2013, p. 501), as a result, we can assume that emotions are inseparable from scientific research.

Michael Polanyi, an English philosopher, chemist and physicist, in his 'Intellectual Passions' declares his commitment to passions, highlighting their heuristic and persuasive functions in science: "The outbreak of such emotions in the course of discovery is well known, but they are not thought to affect the outcome of discovery. Science is regarded as objectively established in spite of its passionate origins. It should be clear by this time that I dissent from that belief; and I have now come to the point at which I want to deal explicitly with passions in science. I want to show that scientific passions are no mere psychological by-product, but have a logical function which contributes an indispensable element to science" (Polanyi, 1974, p. 134). The idea of the importance of intuition and emotions in scientific insights is also shared by Leo Szilard: "The creative scientist has much in common with the artist and the poet. Logical thinking and an analytical ability are necessary attributes to a scientist, but they are far from sufficient for creative work. Those insights in science that have led to a break-through were not logically derived from preexisting knowledge: The creative processes on which the progress of science is based operate on the level of the subconscious" (Lanouette, 1994).

Also relevant is the fact that emotions can act as catalysts for critical thinking. When authors personalize their academic writing, incorporating their feelings and experiences into it, they often engage more profoundly with their material. This can result in a deeper analysis of complex ideas and enable authors to develop a unique voice in their writing. Emotions can drive inquiry, prompting questions and reflections that might not emerge in a purely rational exploration of a subject. “In the Western academic tradition, the writer is an intellectual, a thinker, a user of reason. This identity doesn’t mean that emotions or sensual stimuli are absent from academic writing: indeed, the natural sciences have al-ways depended on acute sensate awareness, detection of subtle differences in appearance, fragrance, flavor, texture, sound, movement; moreover, the arts and humanities would not exist without the scholar’s intense and highly articulated sensual appreciation. As for emotion, every discipline recognizes at the very least the importance of passion in the ability to dedicate oneself to research, acknowledged as often tedious” (Thaiss and Zawacki, 2022, p. 6).

In Russia, the style of scientific presentation and scientific language began to take shape at the beginning of the 18th century. The works by M. Lomonosov, who is considered to be the founder of Russian science, and his followers played a significant role in the scientific style development. At the same time, we know Lomonosov’s verses written by him in order to illustrate some scientific laws and discoveries. His verse “About the Nature of Things. Lucretius” illustrates the proposition that ore minerals are sometimes ex-posed by nature itself. His “Iron, Gold, Copper... “ tells the reader about the birth of metals. Thus, the scientist is sure to have experienced emotions and the desire to express them in a different from academic style way.

Linguists define some specifics of the scientific style: “the complexity of syntactic constructions; lexical, stylistic and compositional stereotyping; the subordination of aesthetic properties to the pragmatic attitudes of the author; the regulated nature of the use of the emotional possibilities of the word; the predominance of objectivity in presentation; a combination of a subjectless (impersonal) method of presentation with the expression of the subjective opinion of the scientist (author); the widespread use of symbols, formulas, graphic constructions, etc. “ (Bocharnikova, 2011, p. 79).

Within the framework of modern scientific discourse, the informative function, which implies regularity, discreteness, correctness, and, on the other hand, the expressive function, which is characterized by markedness, non-discreteness, non-standardness, illogicality, are not opposed to each other. Despite the antinomy, these two components successfully “coexist” and, moreover, “cooperate”, promoting the act of communication (Abrosimova and Bogdanova, 2011, p. 162].

If earlier the opposition of ratio and emotio was clearly expressed in academic communication, now the emotional component is recognized as important on a par with the rational and factual content of the statement. In particular, in educational practice, a scientist often uses proverbs and sayings as an additional means to enhance the expressive function to enhance the information function (Belousova, Epritskaya, 2018). Today we also witness the incorporation of some previously «alien» elements – linguistic expressive means – into academic dis-course, which we will discuss below.

Classical vs Post-Non-Classical Science: from Rigidity to Flexibility

In order to explain this “ratio-emotio” cooperation, it is crucial to record some major changes in post-non-classical science. Changing of the science social status, democratization of scientific discourse. Today one of the primary objectives of academic writing has become to engage the reader. Emotions can serve as an influential tool in achieving this goal. Unlike purely rational arguments, emotionally charged narratives can resonate on a deeper level, promoting better connection between writers and readers. As a result, “the traditionally sanitised academic discourse, which so many scholars have characterized as formal, depersonalised and factual, is acquiring a casual tone more fit for an informal conversation” (Guinda, 2022). All the more so because the interest to scientific topics of non-specialists is increasing today, consequently, there is the necessity for enhanced democratic frameworks facilitating interactions between scientists and lay audiences.

The convergence of social, humanitarian and technical knowledge, and theoretical pluralism. Classical science accepted the truth of one explanatory theory, non-classical science was based on the prin-

ciple of complementarity, post-non-classical science allows the coexistence of many theories about the same objects, each of which claims to be true, and only the transition from one theory to another allows one to get to the heart of the matter. The expansion of the research field, the emergence of cognitive science based on interdisciplinarity has led to the advent of new understanding of scientificity, an expanded interpretation of "scientific rationality", the development of a more capacious conceptual apparatus, including the concepts of "information", "probability", "chaos", etc.

New research tools. A significant innovation of post-non-classical science is the widespread use of the tools called "human-sized" (V. Stepin): objects of genetic engineering, robots, cyborgs, artificial intelligence. These objects raise moral, ethical and legal questions to the scientific community, thus, non-scientific factors have a significant influence on the formation of the science object.

The emergence of new channels and formats for dissemination and popularization of scientific knowledge among the general public. There are numerous innovations in propagation of scientific research: graphical abstracts, videos, presentations, poster presentations; new hosting services (blogs, podcasts, social networks, virtual museums and exhibitions, billboards), and diverse scientific events (lectures, workshops, festivals, contests, marathons). This has become possible due to the affordance of expanded medium context. At the same time this factor has launched a challenge for scientists, "who need to embrace multimodal and multimedia means of communication. Research findings and implications must reach not only multiple stakeholders, but also an audience of laypeople" (Mur-Dueñas and Lorés, 2022).

Is there Anything Wrong with Witty Titles?

There is an opinion among linguists that, despite the fact that authors of scientific papers adhere to the scientific style, the manifestation of the author's uniqueness, the presence of the author's assessment, as well as the use of speech figurativeness in the scientific style are inevitable (Nikolaeva, 2023; Skripak, 2008). Backtracking from rigor is also justified by the desire to convey the scientific knowledge to a wide audience.

These days, when naming academic papers, researchers resort to using not only formal, but also expressive means in order to draw the target audience's attention to their scientific results, to stimulate the public interest to them, by this implementing the phatic and informative functions of the language. There are no longer strict frameworks implying the brevity and clarity of the title. Rather, on the contrary, now some authors, competing with colleagues, create intriguing titles that are far from brevity and clarity, often with a humorous subtext implying "emotional marketing and branding"(Gómez-Cabranes, 2013). The scrutinized analysis of more than 2000 scientific papers titles suggests that "humour in the title can increase a paper's impact" (Heard et al., 2022).

Linguists reveal a direct dependence of the success of the reader's perception of the text on the linguistic techniques used by the author. Here are some examples of modern scientific paper titles found in reputable databases. The Human Microbiome Journal (No. 13, 2019) published an article entitled "The Effect of Having Christmas Dinner with In-Laws on Gut Microbiota Composition" (Clercq et al., 2019). This article received more than 3,300 comments and 850 tweets. Moreover, the article «launched» a chain of further publications, apparently provoked by the unusual and funny title. The further articles are called "Feast Studies: Does Food Disrupt Gut Flora? " (Studien zum Fest..., 2019). We also find an article on a Dutch website entitled "Christmas with the Mother-In-Law May Lead to an Increase in the Number of Stress Bacteria in the Gut" (Weihnachten…, 2019). Although the above articles are not strictly scientific, one can observe the reader's interest in the original paper published in a reputable scientific journal with a high impact factor.

In the scientific journal "Geology" we come across the title of the article "Great Big Boulders I Have Known" (Beaty, 1989). The author uses the personal pronoun "I" as a device for creating expressiveness. The author of the article "Space - The Final Frontier for Economists and Elephants" (Space – the Final Frontier…, 2004) in order to draw readers' attention to his work, uses the precedent statement "Space - The Final Frontier" from William Shatner's speech as Captain James T. Kirk in the popular series "Star Trek". I. Sternin also resorts to the precedent text (related to A. Pushkin's famous quotation from "Eugene Onegin") in the title of his article "How to Make Oneself Respected? A Philologist Speaks about the Urgent" (Sternin, 2017). The title of N.W. Goodman's paper "From Shakespeare to Star Trek and beyond: A Medline search for literary and other allusions in biomedical titles" (Goodman, 2005) also includes

a precedent name and a well-known pop-culture phenomenon. Further titles that contain some unusual or humorous references include "The Hitchhiker's Guide to Flow Chemistry" (Plutschack et al., 2017); "Will Any Crap We Put into Graphene Increase Its Electrocatalytic Effect? " (Wang et al., 2020); "Who's Afraid of the Big Bad Whorf? Crosslinguistic Differences in Temporal Language and Thought" (Casasanto, 2008).

The analysis of scientific article titles showed that the tendency to "freely handle" titles is not so pronounced in Russian journals whose publishers generally require strict, short titles that reflect the essence of the work and exclude the author's eloquence. In this respect, the corpus of the studied material showed that the selected titles from non-Russian Scopus journals on natural science topics allow deviations from strictly sci-entific formulations in favor of an informal and emotional context, while Russian journals impose stricter requirements for titles.

Linguistic means of expressiveness in scientific discourse

In order to illustrate the above, we turn to monographies, Scopus articles and academic texts examples selected from the British National Corpus of English (BNC), the selection is limited by academic contexts.

As is known, in academic writing there has been a tradition of avoiding the use of the personal pronoun "I", replacing it with the pronoun "we". However, today we come across numerous cases of "personifying" achievements through the extensive use of "I": "in many modern scientific works, the linguistic and emotional personality of their authors is increasingly designated through the personal pronoun "I", through the cognitive-emotional position of the author, through their emotional argumentation" (Shahovskij, 2008, p. 269). Thus, we find in one scientific article (Banks, 2018) 18 uses of the personal pronoun "I" in different contexts (I would like to consider; I shall start by looking at how…; I shall do this in some detail; I shall look, rather more briefly, at how this…; I shall consider the implications…; I will consider the use of…; I feel it is useful to…; I shall take as an example the use of…; In the corpus that I was using for a recent study…; I also found passages…; Indeed, in my sample, I noted several examples of English that I would have considered as…; This can, I think, be related to a…; Hence, I would suggest that…, I am doubtful about the possibility…; etc.).

Also, modern scientists note "dramatic" reduction of passive voice structures which have been a feature of academic genre for many years, especially in American English (Seoane, 2006, p.107; Gómez-Cabranes, 2013).

The analysis of the empirical material shows that the revised texts contain lexical and stylistic means of expressiveness, which include:

metonymy (*Acrilic has taken over the art world*) (Lakoff and Johnson, 2004, p. 61);

metaphors (*It should also throw light on how lack of response to iron treatment points to the need for further colonic assessment*) (BNC);

epithets (*More recently Abraham and co-workers have extended this work to the helium-xenon system, where the helium partial pressure allows the degree of inhomogeneous broadening to be varied as a control parameter, with beautiful results*…(BNC); *They became difficult teenagers, leading to disputes with local political authorities. Both suffered violent deaths. The sad consequence on the children's lives of the circumstances of their birth led me to the conclusion that pregnancy in elderly women might not be appropriate and the whole programme was stopped*) (BNC);

intensifiers: extreme, perfect, complete, pure, utter; actually, certainly, clearly, definitely, obviously, really (*Although this basic classification will suffice for the vast majority of hypertensive diabetics, it is extremely important to delineate the numerically small percentage of those whose elevated blood pressure is associated with neuropathy as these will present an additional therapeutic challenge* (BNC); *The oscillation is surprisingly large, up to 25%, even when the one very large variation is excluded*) (BNC);

quantifiers: multitude of, millions of, a few thousand, several thousand, many thousand, a couple of (*Electronic publishing is a rapidly growing area with a multitude of different systems and techniques available*) (BNC);

phraseological units (*While these approaches may have a grain of truth in them, they founder in the evidence of women's actual political activity around their own demands* (BNC); *The acquisition of a stereotype by a subgroup of the population usually works to its detriment, and although perhaps*

preserving a grain of truth in relation to the subgroup's activities, it is also misleading for members of the whole population who use the stereotype) (BNC).

The most frequent syntactic means of scientific text expressiveness include:

inversion (*In terms of social contact, not only did clients in institutional settings receive on-ly small amounts of contact from staff, the majority of people were never ever observed receiving contact from other clients* (Shahovskij, 2008). *Only in 1978 did it become apparent that both effects are necessary, but also sufficient, to produce the observed phenomena)* (BNC);

comparative constructions (*We may now represent the mental capacities of the cerebral hemispheres of an advanced organism in a simple model that gets us far closer to the condition of our own species*) (BNC);

rhetorical questions (*The integration problem: how do we combine knowledge from differ-ent levels? Should the search for a valid path be data-driven or goal-driven?)* (BNC);

exclamatory sentences (*True pedants add the proviso that an edge cannot also be a node. Imagine what the graph would look like if it was!* (BNC) *For such people a systems approach is not a bad idea! Which is not a bad idea either!)* (BNC);

imperative constructions (*Consider for a minute the tenacity that the concept of "form" has had in design even amongst those most determined to eradicate the idea of "aesthetics"* (BNC); *There is always a trivial algorithm for searching in a finite space -- just list all nodes, and examine them in turn)* (BNC);

lexical repetition (*For such people a systems approach is not a bad idea! Which is not a bad idea either!*) (BNC).

It should be noted that the elocutionary possibilities of scientific discourse (for example, in the genre of a modern review) cover not only figures and various transfers, but also informal logic techniques.

Conclusions

Expressiveness of a statement implies mutual relationships between the subject and the object, which influence each other's functioning and are a vivid reflection of the human factor in language, regardless of the type of discourse. The formation and development of a formal scientific style does not mean the absence of passions and emotions in academic discourse, whose indispensable parts are polemics and discussions. Moreover, emotions perform a heuristic function in the process of a scientific experiment, as evidenced by great scientists and their achievements.

Post-non-classical science, having revised the foundations of scientific classics and taking into account the role of man in the study, not only allows expressive means, but also presupposes them. Despite the obvious antinomy, the informative and expressive functions of language in a scientific text successfully "coexist", promoting the act of communication.

The linguistic expressive means of academic writing are: metaphors, metonymies, epithets, intensifying adverbs, quantifiers, inversion, exclamatory and imperative sentences, comparative constructions, repetitions, rhetorical questions, active use of the personal pronoun "I" as a way of self-presentation of the scientist, the use of precedent texts, the assertion of the author's style and gender identity.

In conclusion it should be noted that incorporating emotions into academic writing does pose challenges, particularly in maintaining the reliability and scholarly manner expected in academic contexts. Striking a balance between emotional engagement and critical analysis is crucial. Scientists should learn to discern when and how to express emotions so that they promote their postulates rather than detract from them. It is also important to avoid overly sentimental language or unfounded emotional claims, which can undermine the rigor of academic discourse.

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization A.B. and M.B.; methodology, M.B. and L.A.; writing—original draft preparation, M.B. and L.A.; writing—review and editing, L.A. All authors have read and agreed to the published version of the manuscript.

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Integration of Popular Music in Educational Projects in Higher Education

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Abstract: In order to adequately prepare music education students for their future careers, it is important to include content related to popular music in the curricula, in addition to courses that focus on developing knowledge and skills in classical music. Despite the widespread recognition of its importance, educational knowledge of popular music is a relatively new or even unknown source in teaching music at conservatoires. In Croatia, for example, music teachers who start their careers in schools do not acquire sufficient academic knowledge or professional practice related to popular music during their studies. The music education system has marginalized this genre and there are no separate courses on this topic in the curricula of music education programs. Consequently, content related to popular music is usually integrated into the curriculum through teaching projects. This article presents the implementation, aims and outcomes of three such projects carried out at the Department of Music Pedagogy at the Academy of Music in Pula. The projects are: Film Music Adventure, which considers well-known soundtracks from films, Superstar, which is dedicated to exploring the intersection of rock and opera, and a locally oriented project reviewing musical life in the largest city in the Istrian region, entitled The Seventies Measured by the Metronome: Everyday Musical Life in Pula 1970–1980. Working on these projects engaged students in a dynamic and interactive learning process and increased their engagement, motivation and interest, as well as their knowledge of popular music.

Keywords: *conservatory (music academy), Croatia, popular music, project-based learning.*

Introduction

Popular music is of great importance in today's society as it reflects cultural, social and technological changes and connects people of all ages and backgrounds by creating common points of communication and understanding. With the ubiquity of modern media and digital platforms, popular music now reaches every corner of the world, shaping identities, trends and attitudes. Despite its undeniable presence and influence, it remains underrepresented in the music education and academic settings.

An examination of the curricula of music education at conservatories in Croatia shows a disappointing picture when it comes to the inclusion of popular music. At all Croatian conservatories/universities, the content related to popular music in the music study programs for the education of future music teachers is minimal and sporadic (Marin, 2022). Consequently, prospective music teachers lack sufficient academic knowledge and practical experience in this field. The Croatian academic community continues to adhere to a value-based hierarchy of genres and marginalizes popular music. In formal music education, Western classical music is favored and preferred, which affects students' perception that this is the only *right* or *worthy* music that should be taught.

The introduction of popular music into conservatoire curricula offers numerous benefits for students and institutions alike. It broadens their perspectives and enhances their creativity by encouraging them to explore different genres and forms. As popular music often reflects social movements and global trends, its integration into the classroom helps students to better understand cultural, societal and tech-

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nological changes. In addition, it helps develop critical thinking skills, analytical thinking, teamwork and digital literacy, which are essential in today's rapidly evolving music and media industries. By listening to, experiencing and engaging with popular music, students become familiar with its characteristics, acquire different musical knowledge, learn about the characteristics of different eras, discuss the quality of musical pieces and evaluate them critically. Ultimately, the integration of popular music into the curriculum makes it more attractive and creates a more inclusive and modern educational environment. Because of its familiarity and relevance to students, it encourages active participation, critical thinking and creativity. Cross-curricular approaches, content integration and interdisciplinarity should be considered when teaching popular music.

Years of experience in working with students of the Department of Music Pedagogy at the Academy of Music in Pula, especially through teaching projects (Duraković and Vidulin, 2017, 2020), shows that these projects equip students with a range of professional skills (e.g. music analysis, musicological knowledge, application of various didactic strategies) and extracurricular competences (e.g. IT skills, digital literacy, research methods and public presentation skills). This contributes significantly to their professional and personal development.

In order to improve the models of teaching practice, some of these projects were thematically linked to popular music. As there is no universal methodology for the implementation of project-based teaching, this article describes three projects, outlines their implementation phases, presents the results, explores possibilities for dissemination and discusses the learning outcomes and the types of contexts (intradisciplinary, interdisciplinary and cross-curricular).

Popular Music: Approach and Perspective

Popular music is the subject of extensive research and discussion in musicology, media studies, sociology, cultural studies and other disciplines. Leading theoretical contributions provide insights into its historical development, cultural context and social functions, encompassing production, distribution and consumption, as well as its role in shaping identities, communities and cultural values (Frith, 1996). Its meaning is also explored through the emotional and subjective connections that listeners develop with music (Grossberg, 1997), through analysis of its structures and meanings (Middleton, 2000), and through the impact of technology on its socio-cultural implications, including issues of politics and power (Hesmondhalgh, 2002).

Birrer (1985) categorizes definitions of popular music into four perspectives, which can function independently or in combination. The normative perspective associates popular music with quality judgments and often describes it as less sophisticated than classical music. The descriptive or distinctive perspective identifies characteristics of popular music without value judgments. The sociological perspective examines its social context and functions, including its role in the formation of values, norms and identities. Finally, the technological perspective focuses on the modes of production and distribution and the impact of technology on popular music. While these definitions are helpful in understanding the complexity of this cultural phenomenon, a multidisciplinary approach provides a more comprehensive view of what popular music is and how it functions in different contexts (Middleton, 1990).

These varying perspectives are reflected in the theoretical frameworks for teaching popular music at higher education institutions. Researchers emphasize the importance of a cross-curricular approach to provide a holistic music education that is responsive to students' needs and interests (Campbell 2004, Jorgensen 2003, Regelski and Gates, 2010). Suggested strategies include constructivist methods that encourage active student participation through the creation and performance of music, as well as critical pedagogy that focuses on the theoretical and critical analysis of the sociocultural and political dimensions of music (Elliott and Silverman 2015, Powell and Smith 2024, Wright, 2010).

The integration of technological skills is also crucial, as it enables students to effectively utilize online resources and platforms while connecting popular music to other disciplines such as media studies, sociology, anthropology, and technology. Curricula that incorporate these elements provide students with a comprehensive education that helps them understand various musical practices in the context of a broader social, cultural, and technological environment (Campbell 2004, Jorgensen 2003). Collaborative learning and project-based teaching are increasingly emphasized in contemporary music education, encouraging innovative solutions and deeper engagement with popular music (Goodrich 2022, Przybylski and Niknafs 2015, Sawyer, 2007).

Project-Based Learning: A Model for Improving Teaching

Contemporary education systems often cling to outdated teaching methods, creating a gap between current practices and the demands of contemporary higher education. Rapid societal change requires methodological adaptability and the integration of innovative approaches that motivate students and modernize the educational process (Velasco Moreno, 2023). Project-based learning, which focuses on interdisciplinary projects, offers a valuable model for improving teaching methods.

In project-based learning, students acquire skills in research, scientific methodology and public presentation through interdisciplinary and multimodal approaches. This method engages students in dynamic, interactive learning processes and increases their engagement and motivation. It promotes active learning, creativity, teamwork and skills such as planning, analysis, evaluation, decision-making, time management and presentation. These competencies prepare students for challenges outside the academic environment and prove valuable for their future education and career.

By developing critical thinking, social competence, and practical application of knowledge, students acquire both academic and life skills that are essential for meeting the challenges of the 21st century (Johnson and Johnson 1999, Saavedra and Opfer, 2012). Teachers play a key role in setting goals, encouraging project work and guiding students to practical, impactful results (Meyer, 2002, Meyer, 2002). The sense of accomplishment when a project is completed can be a powerful motivator for further learning.

Recent research provides insights into different approaches to project-based learning and contributes to the understanding and application of modern educational trends (Bell 2010, Boss and Krauss 2022, Thomas 2006, Wurdinger, 2016). Studies also provide examples of teaching projects and strategies for their implementation in conservatoires and offer guidelines for future practice (Hernández and Vicente 2022, Przybylski and Niknafs 2015; Tobias, Campbell and Greco, 2015).

This article follows these trends and presents three popular music projects developed at the Department of Music Pedagogy at the Academy of Music in Pula. These projects are an example of a model for improving teaching methods and promoting innovative approaches to integrating popular music into higher education curricula.

Popular Music at the Academy of Music in Pula: Examples of Project-Based Learning

Project 1. Film Music Adventure

Project description

The educational project entitled *Film Music Adventure*, which dealt with music from famous films, was conducted by four students. The students conceptualized the theme independently and chose the music on which the project was based: James Bond and Skyfall songs from the James Bond films, the Pink Panther theme from the film of the same name, the love duet from Beauty and the Beast, the theme of Darth Vader from Star Wars, the theme from Desperado and the theme from Schindler's List.

Work phases

The first phase involved obtaining the sheet music for the selected musical examples. The students divided up the tasks among themselves and decided who should analyze and perform the individual pieces. If they felt that a piece needed to be rearranged or adapted for a particular instrument or additional background vocals, they involved colleagues who they felt had the necessary skills: few colleagues from the Department of Music Pedagogy, several solo singers and others who played exclusively acting roles.

In the second phase, they researched information about the content, directors and music composers of the selected films, created a historical overview of each film and conducted a brief analysis of each song. At the same time, they rehearsed their performances of the pieces.

In the third phase, after the music pieces were rehearsed and analyzed, they developed a script for

the public presentation and created a schedule for the event. They decided that the presentation should be aimed at a wide audience (primary school pupils, high school students, university students and the general public). To make the presentation more engaging and dynamic, they organized a small ensemble of Academy students playing various instruments (tuba, trombone, violin, flute, accordion) to perform the well-known 20th Century Fox theme recording their performance. They also filmed a glamorous walk down a red carpet and edited the footage with camera flashes and audience applause to create the atmosphere of an Academy Awards ceremony.

They borrowed costumes for roles such as Beauty and the Beast, Darth Vader, Pink Panther and the Detective to enhance their performances. They also made sure that a red carpet was laid out on part of the stage where the project was presented. The mentors helped adapt the script and concept for the public presentation, supervised the rehearsals for the performance and oversaw the harmonic and formal analysis of the music pieces.

Presentation of the project and dissemination

The project was presented in 2019 on the Small Stage of the Istrian National Theater in Pula. The event began with the projection of two video clips on the screen of the theater hall: the theme of 20th Century Fox and a scene of a walk on the red carpet. The students, working in pairs, took the stage one by one to present their descriptions and analysis of selected songs. At the same time, the movie trailers matching the songs were shown on the screen. Each analysis was followed by a live performance of the song.

The appeal and dynamism of the program was enhanced by the inclusion of acting elements: during the performance of the Star Wars theme, a student portraying Darth Vader wielded a lightsaber; during the performance of The Pink Panther theme, a detective humorously attempted to outwit the elusive pink panther, which he eventually succeeded in doing.

The program ended with an Oscar award ceremony where the students presented symbolic *golden statues* to project mentors, professors and fellow students who had contributed to the realization of the project. The 60-minute program received extensive coverage in the local media, further increasing the impact and awareness of the project.

Correlation, knowledge acquisition, skills development and outcomes

In this project, students acquired skills through cross-curricular and interdisciplinary connections. In their work, they used various knowledge they had acquired during their training and correlated music theory disciplines and music history content with music interpretation. They also used knowledge that they had previously acquired through formal and non-formal education and informal learning.

Table 1. Musical competencies of the students – project 1

Cources	Methods	Outcomes
History of Music Knowledge of music literature	historical biographical comparative	analysis and synthesis of musicological knowledge
Harmony Musical Forms and Styles	harmonic and structural analysis of selected songs analysis of musical elements (melody, mood, rhythm, dynamics, agogics, etc.)	analysis and synthesis of theoretical musical knowledge
Piano Solo Singing Guitar	demonstration (performance of selected songs, either solo or in ensembles)	comparison and evaluation of performances
Harmony on Piano Playing Scores Arranging for Ensembles	musical arrangement	creating orchestral arrangements adapting songs for voice and piano, voice, guitar and piano, piano and flute

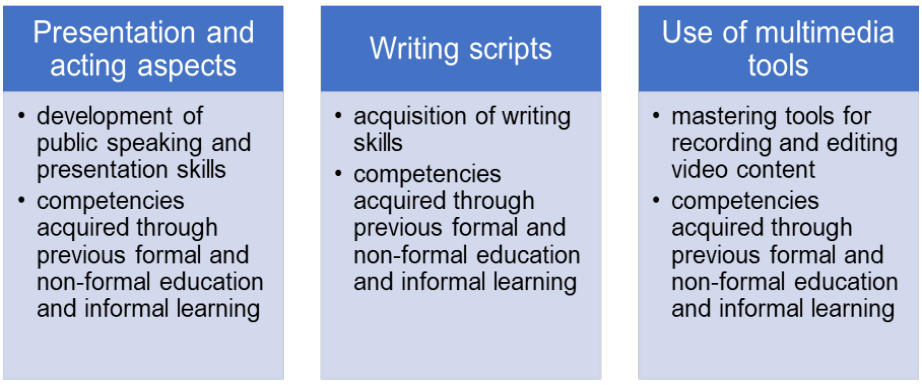

Figure 1. Non-musical skills of the students

Project 2. ***Superstar***

Project description

Six students took part in the *Superstar* project. Preparations began shortly after the COVID-19 pandemic, which led to a somewhat modest realization of the project. It consisted of two parts: a short film in which the students used instrumental excerpts from the rock opera Jesus Christ Superstar as a soundtrack, and a live performance of the song Superstar from the same musical work.

Work phases

In the first preparatory phase, students developed a theme and wrote a script in which all students receive the same mysterious text message consisting of only two words: rock and opera, stating that they need to meet urgently due to a serious situation. At the end of the conspiratorial meeting, during which they discuss the necessary action of merging the incompatible – rock and opera, they decide to rehearse a performance of a song from the rock opera Jesus Christ Superstar. They create a choreography, design costumes, warm up their voices and arrive at the place where they will perform the songs live.

In the second phase, the students rehearsed the performance of the songs and learned how to act out the prepared script. They then filmed scenes with their cell phones in their student apartments and on the streets of the city, recording sounds and edited the video with the mobile application InShot. The humorous and educational video, aimed at compulsory school students, taught viewers the differences between rock and opera, the elements of opera and the differences between opera and rock opera. As the terms rock and opera may seem contradictory at first glance, the film and performance emphasized this contradiction. The video also included educational subtitles defining musical terms. The mentor's role in this project was limited to reading and correcting parts of the script, while the students performed the performance part independently without the mentor's supervision.

Presentation of the project and dissemination

The project was presented at the Eighth Forum of Music Pedagogy Students in 2022. The video was shown first, followed by a live performance in which Judas, Jesus and two groups of singers performed the song. The presentation was internal and intended for students at the Academy of Music in Pula. The recording was uploaded to the Academy of Music YouTube channel.

Interdisciplinarity, knowledge acquisition, skills development and outcomes:

As with the previous project, the students acquired skills through cross-curricular and interdisciplinary connections. During the project, they applied various knowledge they had acquired during their education by linking music theory disciplines, didactical content and music history to the interpretation of the music pieces. They also used knowledge they had previously acquired through formal and informal education and informal learning*.

*The results of non-formal education and informal learning (presentation and acting, script writing and use of multimedia tools) are consistent with the results presented in Figure 1.

Table 2. Musical competencies of the students – project 2

Courses	Methods	Outcomes
Didactics of Music Education Knowledge of music literature	historical comparative	analyzing and synthesizing musicological and music didactical knowledge
Vocal Technique	demonstration (performance of selected songs)	comparing and evaluating performances

Project 3. Popular Music in the Project The Seventies Measured by the Metronome: Pula's Musical Everyday Life, 1970–1980

Project description

This research project was carried out by a group of students. The topic was chosen by the mentor, who noted that there was no published research results on any aspect of musical life in the 1970s and saw this research as pioneering work that was valuable for educating a wider audience and future researchers.

As the project was entirely focused on music history, the mentor gave the students a lecture on the concept of historical musicology, which studies musical phenomena as part of historical and evolutionary processes. The lecture introduced various sources for the study of contemporary history: material, written (e.g. newspapers and periodicals from the past), archival documentation, oral, visual and audiovisual sources (drawings, photographs, maps, illustrations, posters, audio and video recordings) and others.

In the discussion, the students reached a consensus on which sources could be used for this particular project. It was also agreed that the results of the project should be presented in the form of a documentary film. In order to realize this, the research questions focused on determining the target audience and content: Who should the film be aimed at (specialist audience, scientific community or general public) and what should its aims be (educational, informative or evoking memories of the past).

Work phases

The first phase of the research involved collecting newspaper articles. The students had the task of viewing and photographing all music-related articles from the daily newspapers in the university library. For each photo, they had to note the author, the title of the article, the date and the page number.

In the second phase, the students sorted the collected articles into thematic categories: music education, classical music concerts, activities of cultural and artistic associations, opera seasons that take place in the amphitheater during the summer, the work of orchestras and composers, popular music and curiosities.

In the third phase, the collected texts were edited and the script written. The students responsible for the popular music read all the relevant texts, summarized the most important and interesting information and reworked and reshaped the content to integrate it into the film. For visual enrichment, photos, audio and video materials from the 1970s were collected, provided by museums, libraries, radio and television stations, as well as some sources found on YouTube. The introduction was filmed in front of a once-popular discotheque that hosted numerous music events in the 1970s, while the rest of the script was recorded in a studio.

The popular music part of the movie was divided into three major segments: Pop Music, Folk and Newly Composed Folk Music, and Rock and Jazz. Each segment was about the activities of local artists from Pula as well as guest artists from other republics of the former Yugoslavia and abroad. Texts were written to inform future viewers about the popularity of the artists and their reception by the audience in Pula. The film also offered insights into the best-selling records of the time, the music played in dance halls and discotheques, the most popular hits, audience behavior at various events and much more.

Presentation of the project and dissemination

The film was screened at the Tenth Forum of Music Pedagogy Students in 2024 and later broadcast in two episodes on TV Nova in Pula. The public presentation was reported in all local media.

Interdisciplinarity, skills development and outcomes

In this project, students developed their skills through interdisciplinary connections by applying research methods commonly used in the humanities area. They also applied knowledge acquired through formal education, non-formal education and informal learning.

Table 3. *Courses, research sources, methods, and outcomes – project 3*

Courses	History of Music History of Croatian Music Knowledge of Music Literature
Research Sources	articles from newspapers and magazines photographs and posters kept in museums and libraries photographs from private albums video materials kept in the archives of institutions that were active in the 1970s archived radio and television broadcasts
Research Methods	inductive method of analysis and synthesis generalization classification descriptive compilation comparation historical
Outcomes	understand concepts in the context of media coverage research and interpret the content of articles in the context of social conditions analyze, extract, evaluate, compare and critically assess newspaper articles to determine their relevance for project implementation meaningfully combine selected articles into coherent units synthesize and structure texts present and interpret the texts develop public speaking and presentation skills

Conclusion

Given the low proportion of popular music in higher music education programs in Croatia, it is unlikely that students, future teacher are adequately prepared to teach this subject effectively. But, the curricula for compulsory primary and secondary schools prescribe the teaching of content related to the practice of popular music. This means that future teachers will have to rely largely on self-taught knowledge in their work in the classroom unless there are significant changes ih higher education prgorame.

In didactic courses and in school practice, when designing their own lessons, music education students often combine standard teaching units with examples from classical but also popular music. The great interest of students in theses on popular music also shows that many of them would like to study these genres in more depth.

An additional comprehensive curriculum with courses dealing with popular music would better prepare students for their future careers. In the meantime, efforts should be made to integrate popular music through project-based learning, which can greatly enhance their learning experience and increase the public visibility of the academies themselves.

Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization: L.D. and S.V.; data curation: L.D. and S.V.; formal analyses: L.D.; methodology: L.D. and S.V.; writing - original draft preparation: L.D.; writing - review and editing: S.V. All authors have read and agreed to the published version of the manuscript.

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