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In this third issue of 2025 (Vol. 18, No. 3), we are delighted to present seven articles covering various topics. The central research area of the presented articles is the interplay of cognitive, affective, and social dimensions that shape teaching and learning in STEM and physical education contexts, aligning with ERIES's focus on efficiency and responsibility. Across these contributions, three themes stand out: targeted, evidence-based interventions that bolster domain-specific competencies; the strategic integration of technology and collaborative learning to deepen reasoning and engagement; and the imperative to address affective barriers—such as anxiety and social responsibility—to cultivate inclusive, accountable educational environments. Together, these contributions advance the ERIES Journal's mission to disseminate rigorous and innovative research that enhances educational efficiency, promotes ethical accountability, and informs evidence-based pedagogical practice.

In the first article, "Exploration of Spatial Abilities in Pre-Service Mathematics Teacher Education: Testing and Evaluation", Petra Surynková, Vlasta Moravcová, Jana Hromadová, and Jarmila Robová examined how first-year pre-service teachers at Charles University perform on 2D and 3D geometry tasks. They tested cohorts from 2021 to 2023 using identical problem sets targeting subcomponents of spatial ability. Participants excelled in planar rotation but struggled most with spatial visualization; analysis showed that conceptual misconceptions underlay many of the errors. The authors conclude that focused instruction in spatial visualization and deeper conceptual training is essential to improve future teachers' geometry teaching. This paper represents one of the first longitudinal studies using consistent geometry tasks across multiple cohorts. Future work will retest these students at graduation to assess the effectiveness of the intervention.

In the second article, "Assessment of Information and Communication Competence of Future Teachers Based on Laboratory Work in Natural Sciences", Dastan Kabdualiyev, Miroslav Brabec, Aigul Aldabergenova, Petr Benda, and Miloš Ulman examined the impact of integrating ICT into lab courses for prospective physics, biology, and chemistry teachers at Zhetysu University. Employing an experimental design, they compared student cohorts receiving traditional instruction with those using ICT tools, measuring ICT competence via pre- and post-laboratory surveys. Findings show that ICT-enhanced groups achieved significantly greater gains in operational skills, information handling, communication, and critical thinking, alongside higher motivation and engagement in lab work. The study also identified barriers, including unequal access to technology and the need for extensive teacher training. The authors conclude that embedding ICT in natural science laboratories is crucial for developing future teachers' digital competencies and recommend further research on long-term outcomes and optimal ICT strategies across diverse educational settings.

In the third article, "The Role of Personal and Social Responsibility on Future Physical Education Teachers' Bullying Attitudes", Ceren Temiz and István Soós examined how personal responsibility (PR) and social responsibility (SR) shape bullying attitudes among 164 Hungarian physical education teacher candidates in their 3rd to 5th years. They administered questionnaires assessing PR, SR, bullying attitude subdimensions, and analysed the effects of gender, year of study, and teaching experience. Findings show that SR—but not PR—strongly predicts attitudes across the Ignore, Humanistic, Tough, and overall scales, with gender and year also being significant. No effect emerged for teaching experience. The authors conclude that anti-bullying and teacher-education programs should prioritize developing SR to foster safer, more accountable PE classrooms.

In the fourth article, "Predicting University Engagement of Physical Education Teacher Education Students via Three Positive Traits", Joseph Lobo, Jem Cloyd Tanucan, Walton Wider, Kirth Teodosio, Johnlenon Aliser, Jiear Sison, and Ailyn Elbanbuena investigated how life satisfaction, academic resilience, and curiosity predict university engagement—vigor, dedication, and absorption—among 2,730 Filipino PETE students using regression analyses. Curiosity emerged as the strongest and most consistent predictor across all engagement dimensions, academic resilience predicted only dedication, and life satisfaction showed no significant links. The authors conclude that embedding inquiry-based, gamified, and exploratory physical activities in PETE programs is crucial for fostering student involvement and emotional commitment. They recommend modeling curiosity-driven pedagogies throughout teacher training to prepare future educators for dynamic classroom demands. Future research should employ longitudinal and mixed-methods designs to explore contextual influences and validate curiosity constructs in diverse educational settings.

In the fifth article, "Enhancing Pre-service Mathematics Teachers' Proof-Writing Skills: the Effect of a Social Learning Environment Enriched with Dynamic Geometry Software", Tuğba Öztürk and Bülent Güven tested the ISMAT model in a quasi-experimental study with pre-service teachers, comparing 14 weeks of dynamic geometry–supported lessons against traditional instruction. They assessed proof-writing via Senk's framework before and after the intervention. Post-test data show that the experimental group's lowest-reasoning proofs (RP0) decreased from 39% to 14%, while mid- and high-level proofs (RP2–RP4) increased significantly; the control group exhibited only minor changes. Interactive discussions, peer collaboration, and clear distinctions between given conditions and required proofs enhanced conceptual understanding and confidence. The study demonstrates that social learning with dynamic geometry software fosters deeper reasoning, better proof initiation, and coherent justifications. The authors recommend adopting ISMAT-style environments in teacher education to strengthen proof-writing skills. Future work should examine spatial skill training, long-term effects, and the impact of active group engagement.

In the sixth article, "The Positive and Negative Impact of Online Social Ties on PA Behaviour: a Qualitative Analysis in Chinese Adolescents", Min Cui, Anika Frühauf, Anne Kerstin Reimers, Yolanda Demetriou, and Claus Krieger explored how online social relationships influence physical activity among 74 Chinese teens across 13 focus groups. They examined both strong offline ties (peers, parents) and weak or peripheral online ties (fitness influencers, PA-focused communities) through thematic analysis. Positive themes included virtual companionship and motivation during solo exercise or online sessions, while negative themes centered on activity stereotyping and an overemphasis on appearance. The study concludes that effective social media interventions should harness a mix of strong and weak online ties to boost adolescent PA and mitigate harmful stereotyping. It also recommends integrating discussions of negative social media influences into school PE curricula. Future research should empirically test intervention strategies—such as online role modeling, companionship features, and friendly competition—to assess their impact on adolescents' activity levels.

In the seventh article, "The Role of Spatial Anxiety in the Relationship Between Mathematics Anxiety and Spatial Reasoning", Yoppy Wahyu Purnomo, Firda Nur Fadhilah, Ucu Sumusiasih, Rina Dyah Rahmawati, and Yeni Fitriya surveyed 477 Jakarta elementary students (grades 4–6) to examine how spatial anxiety mediates and moderates the adverse effect of math anxiety on spatial reasoning. Employing cross-sectional questionnaires and PROCESS macro mediation/moderation analyses, they found that higher math anxiety directly impairs spatial reasoning and indirectly does so via increased spatial anxiety. This math-to-reasoning link was strongest at low to moderate spatial anxiety but weakened when spatial anxiety was high. Female students exhibited stronger anxiety–reasoning associations than males, and older cohorts reported greater math anxiety. The authors conclude that priority should be given to interventions reducing math anxiety—tailored to students' spatial anxiety levels—to enhance spatial reasoning. These findings emphasize the responsibility of educators to integrate affective-barrier mitigation alongside cognitive skills development for more efficient and equitable spatial learning.

In closing, we extend our gratitude to all authors whose innovative research enriches the ERIES Journal and to our reviewers for their meticulous evaluations that uphold our commitment to academic excellence. Your rigorous work ensures each article advances our understanding of efficiency and responsibility in education and science. We hope this issue sparks new ideas and practical approaches for educators, researchers, and policymakers. For the latest ERIES Journal news—including updates on our most cited papers, upcoming events, and calls for special issues—follow us on LinkedIn.

Sincerely

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CONTENT

Full research paper

EXPLORATION OF SPATIAL ABILITIES IN PRE-SERVICE MATHEMATICS TEACHER EDUCATION: TESTING AND EVALUATION

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ABSTRACT

Pre-service mathematics teachers often struggle with spatial ability, which negatively affects their success in solving geometric problems. Evaluating and developing these abilities is therefore an essential part of their university education. This paper presents findings from the initial phase of a long-term study focused on assessing the spatial ability and conceptual knowledge of first-year pre-service teachers at Charles University. Each year from 2021 to 2023, newly enrolled students were tasked with completing tests focused on 2D and 3D geometry, classified according to specific subcomponents of spatial ability. The results show that the students were most successful in planar rotation tasks, with the tasks requiring spatial visualisation proving to be the most challenging. Conceptual misconceptions were identified as a key factor contributing to errors in solving geometric tasks. These findings highlight the need for targeted instruction and training to improve spatial thinking and conceptual understanding in teacher education, with a view to improving the quality of the geometry teaching they provide in the future.

KEYWORDS

Conceptual knowledge, efficiency in geometry education, planar and spatial geometry, pre-service mathematics teacher education, spatial ability, testing spatial abilities

HOW TO CITE

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Highlights

- *Tasks involving spatial visualisation pose the most difficult challenge for pre-service mathematics teachers.*
- *Planar tasks are easier for pre-service mathematics teachers than spatial ones.*
- *Deficiencies in conceptual knowledge contribute in varying degrees to errors in spatial geometry tasks undertaken by students.*

INTRODUCTION

Many students, including future mathematics teachers, face persistent difficulties when solving geometric problems. Research has repeatedly shown that geometric tasks in a three-dimensional space tend to be more demanding than planar tasks (Ismail and Rahman, 2017). A broader study of 1,357 students (Grades 4–9) found that even combined spatial abilities were insufficient to handle problems that required more than one step of spatial reasoning. Students' success depended on the integration of domain-specific geometric knowledge, such as knowledge of the elements, properties and concepts of geometric figures (Fujita et al., 2020). Other studies have also shown that difficulties in geometry are often related to underdeveloped spatial abilities (Sorby and Panther, 2020) or limited conceptual understanding (Rittle-Johnson and Schneider, 2015). It is important to address students' difficulties with geometry learning during their university education—especially in the case of future mathematics teachers.

Theoretical Framework

The success in solving geometric problems critically depends on spatial ability. Lohman (1979) describes *spatial ability* as the ability to generate, retain, retrieve and transform well-structured visual images. Lean and Clements (1981) define spatial ability as the ability to formulate mental images and to manipulate these images in the mind. A similar definition is presented by Linn and Petersen (1985), who state that spatial ability generally refers to the skill of representing, transforming, generating and recalling symbolic, non-linguistic information. Sorby (1999) makes a distinction between *spatial ability* and *spatial skills* – spatial ability is considered an innate capability for visualisation, while spatial skills are acquired through training and learning.

Nevertheless, these terms are closely interconnected; it is difficult to distinguish between them. In line with literature, the term spatial ability is used uniformly here, with the way in which the ability was acquired, not examined.

Extensive research on spatial ability has led to the development of detailed categorisations of its subcomponents. These categorisations have also been modified and expanded over time. However, there is no clear and consistent model for these subcomponents of spatial ability. For example, McGee (1979) described two major subcomponents (factors in his terminology) of spatial ability – *spatial visualisation* and *spatial orientation*. This categorisation is based on the mental processes used for solving certain tasks. Lohman's (1979) classification consists of three basic spatial ability subcomponents – *spatial relation*, *spatial orientation* and *visualisation*. Carroll (1993) identified five major subcomponents of spatial ability – *visualisation*, *spatial relations*, *closure speed*, *flexibility of closure* and *perceptual speed*. The number of underlying subcomponents of spatial ability seems to vary across studies. However, *visualisation*, *spatial relation*, *mental rotation* and *spatial orientation* are commonly recognised as relevant subcomponents of spatial ability in current research (Maresch and Posamentier, 2019). These subcomponents are considered in the presented research because they best suit the types of geometric tasks applied. In the following text, each subcomponent of spatial ability is described. We also provide examples of typical tasks in which it is used.

The subcomponent *visualisation* is usually described as a general subcomponent of spatial ability. This subcomponent is defined as the ability to think of changes in objects, changes in position, orientation, or internal relationships. This implies that we mentally manipulate or alter the imagined object or its components. According to Maresch and Posamentier (2019), this can include tasks such as mentally folding objects from their nets and vice versa, identifying the opposite sides of a cube from its net, folding a piece of paper and cutting it mentally, completing cubic nets, drawing a net of a solid figure with patterns on its sides from its 3D model, and so on.

Spatial relation is a crucial subcomponent of spatial ability when assembling and organising objects in both two-dimensional and three-dimensional spaces. This subcomponent involves understanding how various parts of an object fit together and how these parts relate to each other in a three-dimensional space. This ability is essential for tasks that require comparing various objects, mentally manipulating and assembling them, and forming a complete structure from separate elements. Spatial relation shares some common features with the visualisation subcomponent but demands a more specific kind of mental manipulation, with emphasis placed on the arrangement and interaction of parts within a whole object. Typical tasks, which can be included here, are the problem of packing luggage (figuring out the most efficient arrangement of items), finding the matching parts from shown structures which can be used to fill another given structure, cutting objects into two parts, building models from small cubes, which involves calculating the number of cubes needed, and so on.

Mental rotation is a subcomponent of spatial ability involving the ability to imagine the rotation of both two-dimensional and three-dimensional objects. Mental rotation tasks typically require the identification of geometric objects, often presented in various positions, and their mental rotation. A common challenge is determining whether two rotated objects are identical (the classical Mental Rotation Test), finding one different object among others, rotating an object around an axis, determining around which axis the object must be rotated to get to the new position, and so on. Furthermore, these tasks usually test the speed with which the problem is solved.

Spatial orientation is a subcomponent of spatial ability which is required for mental orientation in a three-dimensional space. This ability involves understanding and mentally moving around a spatial arrangement of objects. This aspect requires individuals to imagine an object's appearance from various viewpoints. This means that instead of moving the objects in our minds, we mentally shift our own perspective. Tasks assessing spatial orientation often include determining the viewpoints in a 3D map, figuring out from which direction relative to the initial one we observe an object, and given a top view of a parking lot with labels, deciding how these labels would appear when viewed from different perspectives.

Currently, researchers also focus on the identification and description of strategies for solving geometric problems. Traditional research methods regarding subcomponents of spatial ability typically assume that tasks within a specific category are solved using the same intended strategy. However, based on the findings in literature (Maresch and Posamentier, 2019; Kozhevnikov and Hegarty, 2001) and our own experience working with students, it is evident that geometric tasks are approached differently by individuals. We designed a test with geometric tasks, keeping in mind our aim to assess specific subcomponents of spatial ability. While these tasks were primarily designed to test specific subcomponents of spatial ability, dividing them into strictly defined categories can prove challenging. For example, it is possible that the categories overlap, meaning a single task may assess more than one subcomponent of spatial ability. Consequently, the boundaries between task categories cannot distinctly be set, reflecting the individualised approaches of students in problem-solving, as is highlighted in other research publications (Carroll, 1993; Kozhevnikov and Hegarty, 2001). This realisation underscores the complexity of spatial ability assessment, revealing that while tasks are designed with specific spatial ability in mind, they often intersect across multiple spatial ability domains.

Spatial ability is a crucial aspect of intellectual ability. Research has shown that regular training can significantly strengthen this skill. A number of scientists support the idea that targeted interventions can improve spatial ability and have explored effective methods for its development (Gold et al., 2018; Lowrie et al., 2019; Prieto and Velasco, 2010; Šafhalter et al., 2022; Sorby and Baartmans, 2000).

Spatial ability and its subcomponents are usually evaluated through standardised tests. These tests typically focus on a specific aspect of spatial ability, requiring participants to solve similar tasks that vary in complexity. In certain tests, researchers not only evaluate the accuracy of participants' responses but also take into account the speed at which they answer. One well-known test is, for example, the *Mental Rotations Test* (Vandenberg and Kuse, 1978) or its redrawn, modified version, called MRT-A (Peters et al., 1995). These tests assess the mental rotation component of spatial ability. Although other tests exist, none of them were suitable for our research. However, they provided inspiration for developing a completely new test for our students. The primary aim was to assess not just one, but all four defined subcomponents of spatial ability, while also taking into account the important role of conceptual and procedural understanding in mathematics education. The test therefore not only assesses spatial ability, but also evaluates students' understanding of mathematical concepts and their ability to apply procedural knowledge.

A number of research studies have shown a link between performance on tests of spatial imagination and mathematical achievement (Cheng and Mix, 2014; Harris, 2021; Resnick et al., 2020; Sorby and Panther, 2020).

Effective evaluation requires assessing students' spatial abilities as well as their understanding of concepts and procedures. Conceptual and procedural knowledge are considered two key cognitive principles in mathematics. The first is usually defined as 'comprehension of mathematical concepts, operations, and relations' (Kilpatrick et al., 2001: 5), or simply as 'knowledge of concepts', because 'more recent thinking views the richness of connections as a feature of conceptual knowledge that increases with expertise' (Rittle-Johnson and Schneider, 2015: 1119). Procedural knowledge is understood as 'the ability to execute action sequences (i.e., procedures) to solve problems' (Rittle-Johnson and Schneider, 2015: 1120).

Conceptual and procedural knowledge are closely related. While many concepts in the field of arithmetic arise from mathematical processes (Dienes, 1967), in geometry, the child first perceives the concept and procedural knowledge follows (Hejný, 2000). Researchers generally agree that the development of conceptual knowledge improves procedural knowledge rather than vice versa (Hecht and Vagi, 2010; Rittle-Johnson and Schneider, 2015; Rittle-Johnson et al., 2015; Rittle-Johnson et al., 2001; Star, 2005). Furthermore, according to Son (2006), pre-service teachers have limited conceptual knowledge in the field of geometry and tend to rely on procedural knowledge.

Many studies have found an association between spatial ability and mathematical ability (e.g., Sorby and Panther, 2020; Young et al., 2018). On the other hand, Xie et al. (2020) point out that an increasing number of research studies demonstrates that associations between spatial and mathematical ability may not be consistent across all spatial and mathematical components. They analysed studies published in 2008–2018, investigating the relationship between spatial and mathematical abilities. They did not prove a causal relationship between these abilities, but suggested that logical reasoning was more strongly associated with spatial ability than numerical and arithmetical ability.

It is generally known that 3D geometry problems tend to be more difficult for students than 2D geometry problems. This is confirmed, for example, by a study conducted by Ismail and Rahman (2017). This study found significant differences in the examination of 2D and 3D formations at the level of analysis and informal deductive reasoning among students who used GeoGebra. These students were more successful with 2D shapes.

The difficulty of 2D and 3D tasks for students may not only depend on the level of their spatial ability but may also be related to the formulation of the tasks or their representation. For example, solving a problem in a 3D computer environment can be easier than in a 2D environment, as the student can visualise the spatial situation from different points of view.

Research Aims and Questions

While both spatial ability (including its subcomponents) and conceptual knowledge have been extensively studied in mathematics education, they are usually analysed separately. Our study introduces a novel perspective by combining these two dimensions in the analysis of specific geometric task types: we identify which subcomponent of spatial ability is required for particular task types, we examine how deficiencies in conceptual knowledge influence students' success or failure, and we apply this approach in the university setting of pre-service mathematics teacher education. This approach offers valuable new insights into students' difficulties in geometry. The findings can help improve university geometry courses by showing which topics students struggle with and need more support in.

Within this context, our research aims to assess Czech students' proficiency in solving diverse geometric problems. To this end, both planar and spatial tasks were included to examine students' performance across these domains. While it is generally known that students perform better in planar geometry than in spatial geometry, our study goes beyond this general comparison by analysing students' success in specific task types targeting different subcomponents of spatial ability and by examining how deficiencies in conceptual knowledge contribute to errors. This detailed analysis enables the determination of what tasks are more difficult. Based on the students' results, courses on geometry, which students attend during their university studies, can be modified. Specifically, the study targets pre-service mathematics teachers at the Faculty of Mathematics and Physics, Charles University.

In line with the above, the following research questions were formulated:

- RQ1: What is the students' success rate in individual geometric tasks (also with consideration for differences between men and women)?
- RQ2: In which type of geometric tasks targeting various subcomponents of spatial ability do students perform best/worst?
- RQ3: Are students more successful in the planar or in the spatial geometric tasks?
- RQ4: How do deficiencies in conceptual knowledge contribute to students' errors in understanding tasks?

The paper is organised as follows. The Materials and Methods section outlines the test used to assess spatial ability among students, including a detailed explanation of the research methodology. This is followed by the Results section, which presents task success rates, compares male and female performance, examines the different subcomponents of spatial ability, and contrasts planar versus spatial tasks. Furthermore, the impact of conceptual knowledge on performance in geometric tasks is examined. The Discussion section then contextualises the findings within the framework of international studies and addresses each research question individually. The paper concludes with a concise summary, suggestions and ideas for future work.

MATERIALS AND METHODS

Research Context and Participants

Throughout the period of the research, the primary focus was on testing the spatial abilities of pre-service mathematics teachers at the beginning and end of their university studies. In this paper, only the results from first-year students are presented, as these participants have not finished their studies yet. The aim is to analyse students' success in geometric tasks designed to evaluate specific subcomponents of spatial ability alongside their conceptual understanding. A key component of the assessment also involves an evaluation of students' conceptual knowledge in order to provide a more comprehensive understanding of their proficiency in geometry.

Year	Number of students (women/men)	Test format	Time limit (standard/extended)	Number of tasks
2020 (pilot)	36 (25/11)	online	30/40	22
2021	36 (17/19)	in-person	30	26
2022	25 (10/15)	in-person	30	26
2023	25 (11/14)	in-person	30	26

Table 1: General characteristics of the testing, 2020–2023 (source: own data)

The students who participated in the test were pre-service mathematics teachers in the first year of their university studies, i.e. newcomers to the faculty (Faculty of Mathematics and Physics, Charles University, Czech Republic). The testing was repeated four times: in the years 2020 (pilot study, Surynková et al., 2021), 2021, 2022 and 2023, always with different groups of students. The general characteristics of the testing are summarised in Table 1.

Test Design and Development

The geometric problems in the test are designed so that a specific spatial ability is tested by solving them. Each task also assesses certain conceptual knowledge in geometry. In the first year of testing (i.e. 2020), the test consisted of 22 individual geometric tasks. After analysing this initial test, which served as a pilot version, the authors revised it to better balance the complexity of the tasks, aiming to enhance the graphical clarity and comprehensibility of the task descriptions. An additional task focused on planar geometry was also added to further diversify the range of problems. Compared to the pilot version, four tasks were added and four were modified. As a result, in the subsequent years (2021, 2022 and 2023), the test consisted of 26 individual geometric tasks. The tasks are numbered from 1 to 14, with some divided into related subtasks, making a total of 26 tasks. When describing the tasks, the notation Task 12.1, for example, refers directly to a specific subtask, while the notation Task 12, for example, indicates that the results pertain to all its subtasks.

Task Categorisation

A brief description of the tasks from the final version of the test from years 2021, 2022 and 2023 is presented in Table 2, where, among other data, the individual task success rate across the years is provided (column **M**). The tasks are primarily divided into two groups – **2D** (two-dimensional tasks) and **3D** (three-dimensional tasks). The test includes four types of tasks focused on subcomponents of spatial ability: visualisation (**V**), spatial relation (**SR**), mental rotation (**MR**) and spatial orientation (**SO**). The categorisation of the tasks into these types was thoroughly discussed within the team, drawing upon professional literature and the team members' experience. It is important to note that some tasks may fall into multiple categories or may not be typical for a given category (denoted by a dot in brackets); their inclusion is based on professional judgement (the authors of the test have dedicated themselves to teaching geometry and training spatial skills for many years) and the specific objectives of the test. All the tasks test properties of elementary objects in a plane and in a space such as a straight line, circle, solid figure, etc. Other specific conceptual knowledge areas are listed in Table 2.

Procedure

The test begins with preliminary questions about the participant, including the student's name, age and study specialisation. These data indicate the fundamental characteristics of the students who complete the test. The test is not anonymous because the research is planned as long-term research, i.e. The same group of students will be tested in the future again. All students were informed about the objectives and long-term nature of the testing.

The standard time limit for the test was 30 minutes; the extended time limit for students with special needs was 40 minutes. The students solved the test individually during regular courses.

The students were also asked for their opinion on the difficulty of the test and the strategy they used to solve the individual tasks. The students wrote these comments voluntarily. A comprehensive analysis of these comments was not undertaken. Instead, we only examine comments relating to specific tasks, which are discussed in the Discussion section.

Data Analysis

The acquired data were processed both quantitatively and qualitatively. The absolute and relative frequencies of students' answers were determined, with certain dependencies observed. We compared the results of students in individual tasks, across the subcomponents of spatial ability, and also examined the performance differences between men and women. Furthermore, we analysed the outcomes of tasks related to planar versus spatial geometry and investigated the impact of conceptual knowledge on the results. The statistical significance of dependencies between the obtained data was examined by applying Pearson's χ^2 test (which could only be used for some subtasks) and Fisher's exact test (always used due to the conditions not being met for the χ^2 test). To evaluate student comments, we employed qualitative methods and categorised the comments into groups for further analysis.

	No.	M	V	SR	MR	SO	Tested conceptual knowledge	Task characteristics
2D	5.1	91.86			•[1]		- angle of rotation - sign of an angle - rotation around a point - identification of the size of an angle in the square grid	rotating objects around a point in a plane
	5.2	86.05			•[1]			
	5.3	77.91			•[1]			
	5.4	84.88			•[1]			
	8.1	96.51		•			- properties of a circle - number of common points (intersections) of two circles - external and internal tangency of two circles - relationship between radii and circle centre distances	the relative positions between two circles in a plane (solved without pictures)
	8.2	95.35		•				
	8.3	63.95		•				
	9.1	69.77		•			- properties of a circle - number of common points (intersections) of two circles - external and internal tangency of two circles - relationship between radii and circle centre distances - the notation and the meaning of conjunction	the relative positions between two circles in a plane (solved without pictures)
	9.2	70.93		•				
	9.3	84.88		•				
	12.1	97.67			•		- rotation around a point - direct and indirect congruence	rotating objects around a point in a plane
	12.2	98.84			•			
	12.3	100.00			•			
	12.4	100.00			•			
3D	1	84.88		(•)		•	- determination of a plane - intersection of two planes - intersection of a line and a plane - determination of the sides of a cut (two points, parallel lines)	cross-section of solids
	2	90.70		(•)		•	- determination of a plane - intersection of two planes - intersection of a line and a plane - determination of the sides of a cut (two points, parallel lines)	cross-section of solids
	3.1	52.33	•				- determination of a plane - distinguishing of positional and metric properties - parallel lines - skew lines - intersecting lines	the relative positions between two lines in the space
	3.2	70.93	•					
	3.3	60.47	•					
	4	80.23			•		- rotation around a cube edge - skew lines	finding rotated object among others in the space
	6	98.84		•			- measurement of planar objects	assembling cut objects into parts in the space
	7	95.35		•			- measurement of planar objects	assembling cut objects into parts in the space
	10	91.86	•				- top, front and side view of an object - visibility of solid figure edges	identifying the object from top, front and side view
	11	79.07	•				- top, front and side view of an object - visibility of solid figure edges	identifying the object from top, front and side view
	13	89.54			•		- rotation around an axis - top view of an object - Cartesian coordinate system	rotating objects around axis in the space and its projection into a plane
	14	70.93			•		- rotation around an axis - top view of an object - Cartesian coordinate system - composition of transformations	rotating objects around axis in the space and its projection into a plane

[1]*Atypical mental rotation task because the students were asked to determine the size of an angle and its sign.*

Table 2: Categorisation of geometric tasks with brief description, 2021–2023 (source: own data)

RESULTS

Success Rate of Individual Tasks

Initially, the individual task success rate was analysed. Subtask 3.1 was performed the worst, with an average success rate of 52.33% across all tested years (2021–2023). Students also performed poorly on Subtask 3.3, which had an average success rate of 60.47% across all years. Other notable tasks include 8.3, with a 63.95% success rate, and 9.1, with a 69.77% success rate. Subtasks 12.1, 12.2, 12.3 and 12.4 were solved by students almost flawlessly (respectively, 97.67%, 98.84%, 100.00%, 100.00%). Tasks 6 and 7 were also performed well, with success rates of 98.84% and 95.35%, respectively. Subtasks 8.1 and 8.2 were also solved relatively well across all years, with success rates of 96.51% and 95.35%, respectively. Interestingly, Subtask 8.3 had a significantly lower score of 63.95% despite being of the same type.

An analysis was also undertaken of the tasks performed consistently over the years, i.e. those tasks students performed either consistently successfully or consistently unsuccessfully over the years. This was determined by identifying the smallest standard deviations from the average success rate of a task over the years. Consistently successful subtasks were 12.3 ($\sigma = 0\%$), 12.4 (0%), 12.2 (1.33%), 12.1 (1.68%) and 9.3 (2.07%). For the least successful tasks, the low scores were not consistent across all years. This means that a task in which students made errors in one year was solved successfully in other years. For example, Subtask 3.3 had a success rate of 48.00% in 2022, but improved to 68.00% in 2023. Likewise, Subtask 9.2 had a success rate of 58.33% in 2021, whereas in 2022 and 2023, it was 80.00%.

Men and Women

For all tested years, the average score of the men was slightly better than that of the women, as shown in Table 3. The χ^2 test and Fisher's exact test (which was used as a control) confirmed that, with few exceptions, these differences were not statistically significant (at the 5% level of significance). In the analysis of the success rates of men and women in individual tasks, statistically significant differences in favour of men were found only in Subtasks 8.3 ($p = 0.0236$) and 9.1 ($p = 0.0373$) across all years (both tasks are among those with the lowest scores).

	Men	Women	Overall
2021	81.58	77.60	79.70
2022	87.44	85.38	86.61
2023	88.46	86.36	87.54
2021–2023	85.33	82.18	83.94

Table 3: Average scores of all participants by gender and year (relative frequencies expressed as percentages), 2021–2023 (source: own data)

SUBCOMPONENTS OF SPATIAL ABILITY

Some tasks fall into multiple categories (see Table 2). These tasks were statistically included in all considered categories. The least successful was the subcomponent of spatial representation *visualisation*, where the average success rate was 70.93%. Across the years, this did not vary significantly. Other categories were comparable, with *spatial relation* at 85.12%, *spatial orientation* at 87.79%, and *mental rotation* at 88.90%. A summary is presented in Table 4.

Year	V	SR	MR	SO
2021	68.33	79.72	84.85	81.94
2022	72.80	88.80	90.91	90.00
2023	72.80	89.20	92.73	94.00
2021–2023	70.93	85.12	88.90	87.79

Table 4: Success rate of tasks by year according to the subcomponents of spatial ability (relative frequencies expressed as percentage), 2021–2023 (source: own data)

Planar and Spatial Tasks

The success rate of planar versus spatial tasks across the years was also examined. A consistently higher success rate in planar tasks was observed compared to spatial tasks in each of the years 2021, 2022 and 2023, and on average across the years (see Table 5).

	Planar tasks	Spatial tasks
2021	81.94	77.08
2022	90.57	82.00
2023	90.86	83.67
2021–2023	87.04	80.43

Table 5: Success rate of planar and spatial task by year (relative frequencies expressed as percentage), 2021–2023 (source: own data)

Fourteen of the 26 tasks in the test focused on exploring spatial ability in a plane. These were Subtasks 5.1–5.4, 8.1–8.3, 9.1–9.3 and 12.1–12.4 (see Table 2).

The higher success rate of students in the planar tasks is also evidenced by the fact that Task 12 on the rotation of letters and symbols in a plane was the most successful overall, as the average success rate in its four subtasks was 99.15% (the arithmetic mean of the success rate of four subtasks). In the other plane tasks, the average success rate over the three years of the research was as follows – 85.17% (Task 5), 85.27% (Task 8) and 75.19% (Task 9).

Influence of Conceptual Knowledge

It is assumed that the failure of students is also related to deficiencies in conceptual knowledge. The test included tasks specifically designed to assess students' understanding of key geometric concepts, not only their spatial ability. To check whether respondents were consistent in their answers, we identified subtasks that test the same conceptual knowledge and verified them using the χ^2 test and Fisher's exact test (at the 5% level of significance). This process was applied to Tasks 5, 8 and 9. It was found that, for example, associations between correct answers in Subtasks 8.3 and 9.2 were statistically significant (p = 0.0058). A somewhat lesser dependency was also confirmed for Subtasks 8.2 and 9.1 (p = 0.0805). The deficiencies in conceptual knowledge are addressed in more detail in the Discussion section, where, in addition to the mentioned tasks, Task 3 is also discussed.

DISCUSSION

It can be generally observed that performance was significantly weaker in 2021 compared to the other two years, which were relatively comparable. This raises the question of whether the impact of the COVID-19 pandemic might have contributed to these differences (Betthäuser et al., 2023; Moliner and Alegre, 2022). The shift from traditional classroom settings to remote learning during the pandemic could have affected students' cognitive abilities. However, the influence of COVID-19 on educational outcomes is not further investigated in this paper.

RQ1: What is the students' success rate in individual geometric tasks?

In our research, the success rate for individual tasks for all students ranged from 52% to 100%. The problem tasks caused difficulties for more or less all monitored years, but sometimes there were more significant differences between years.

In the most successful task (Task 12), students were required to identify from eight options the image that is not directly congruent with the given one (see Figure 1 in which Subtask 12.2 is depicted). Other tasks that were performed well were Tasks 6 and 7.

Subtasks 8.1 and 8.2 were also among the planar ones that were successfully performed. However, Subtask 8.3, which is similar, was performed one of the worst. More information about Subtasks 8.1, 8.2 and 8.3 is provided under the discussion relating to RQ4.

The task that was performed worst of all was Subtask 3.1, which involved determining the relative positions of straight lines in a 3D space (see also discussion relating to RQ4).

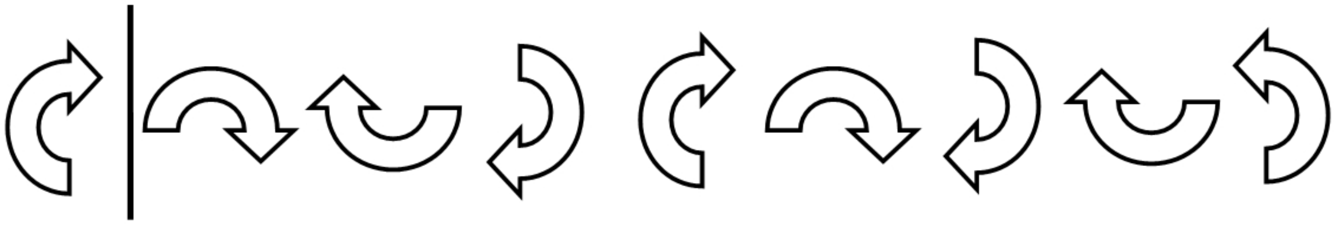

Figure 1: Task 12.2 – Identification of the drawing which is not directly congruent with the given one on the left, 2021 (source: own drawing)

The average score of men on the test was better than the average score of women across the three years of testing. With exception to Subtasks 8.3 and 9.1, these differences were not statistically significant. This result is consistent with other research (Kambilombilo and Sakala, 2015; Halat, 2008), which demonstrated no statistically significant difference between male and female pre-service mathematics teachers with reference to geometric thinking levels. Likewise, no statistically significant differences between males and females in solving geometrical tasks was observed in our research, with only a slight difference in favour of males for several tasks in the earlier research (Moravcová et al., 2021).

RQ2: In which type of geometric tasks targeting various subcomponents of spatial ability do students perform best/worst?

In our research, we tested the students' performance in geometric tasks targeting various subcomponents of spatial ability. The greatest challenge was found to be posed by tasks involving *spatial visualisation*, with an average success rate of only 70.93% over the three years. In contrast, tasks requiring *mental rotation* showed the highest success rates, at 88.9% (on average over the three years).

Tasks involving spatial visualisation required, for example, identifying the spatial object that matched the given top, front and side views in a three-dimensional coordinate system. The correct object had to be selected from four provided options (see Figure 2).

Comparing our findings with international literature reveals both similarities and differences. International research in this field often points out that spatial visualisation is a complex aspect of spatial ability (Lohman, 1979), which aligns with our observation that spatial visualisation is the most challenging for students. Lohman (1979) defined spatial visualisation tasks as complex mental transformations that are considered more difficult than other spatial tasks, which often involve simpler transformations like rotations. Spatial visualisation tasks often involve not only rotating but also manipulating objects in ways that go beyond

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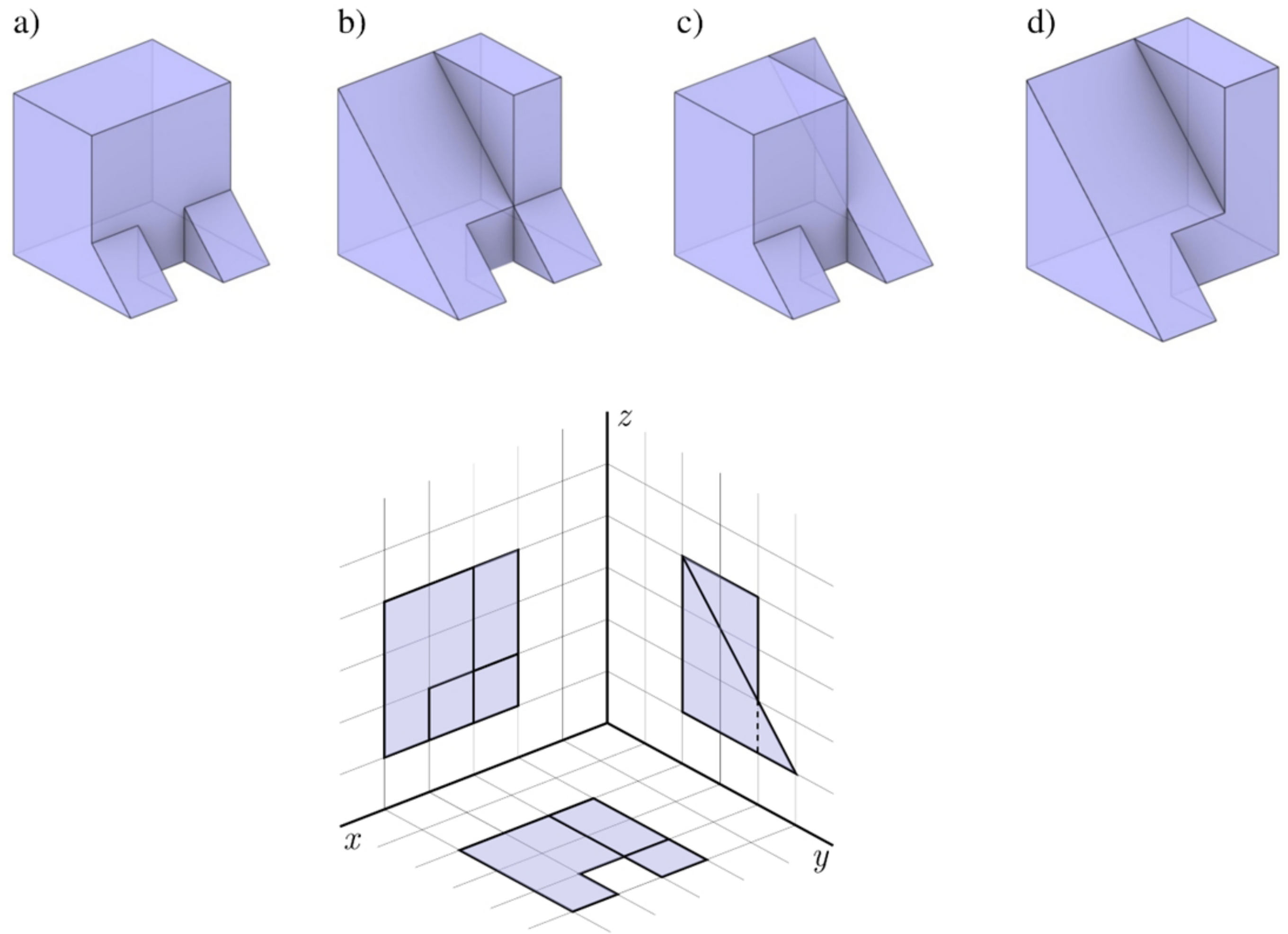

Figure 2: Task 11 – Identification of the object from top, front and side views, 2021 (source: own drawing)

simple rotation. We also observed that the success rates were higher in tasks that required less cognitive load for manipulation, as discussed by Sorby (1999).

For example, Uttal et al. (2013), in their meta-analysis, discuss the variable difficulty levels of spatial tasks among students and highlight the effectiveness of targeted training to improve specific spatial abilities. Another pivotal study by Sorby and Baartmans (2000) demonstrated the long-term benefits of spatial training for engineering students. The lower success rates of our students in visualisation tasks suggests a need for similar interventions.

In tasks involving mental rotation, important characteristics that could affect performance include the angle and axis of rotation. International literature suggests that mental rotation abilities can be assessed comparably, whether using simple cardinal-axis rotations or more complex skewed-axis rotations (Nolte et al., 2022). While our students performed well in mental rotation tasks, international studies do not suggest that mental rotation tasks are generally easier than other spatial tasks. Usually, mental rotation tasks are tested separately due to their distinct cognitive demands.

RQ3: Are students more successful in the planar or in the spatial geometric tasks?

In our research, pre-service mathematics teachers were more successful in solving 2D problems than 3D problems. Also contributing to the higher success rate of 2D problem solving is the fact that the highest scoring tasks across all three years of testing were the four planar tasks 12.1–12.4 (see Results section). However, it should be noted that some subtasks of 2D Tasks 5, 8 and 9 were performed worse. More on this is provided under the discussion relating to RQ4.

These results can be related to the fact that the Czech national mathematics curriculum for lower and upper secondary schools (MEYS, 2005; 2007) focuses more on students' outcomes in a plane than in a 3D space. This fact is also confirmed by our task analysis of state entrance tests to secondary schools and of the graduation tests for the last four years; the ratio between the number of planar and spatial tasks is approximately 3:1.

The better results of pre-service teachers in 2D tasks correspond to international research results with other respondent groups (Ismail and Rahman, 2017). Also, Bruce and Hawes (2015), in their research related to a problem-solving intervention on 2D and 3D mental rotation by children (aged 4–8 years), found that all age groups demonstrated significant gains in their 2D mental rotation performance; the effects were higher and more consistent than those observed on the 3D tasks.

Figure 3 is an example of one of the 3D tasks, even though 3D tasks delivered lower success rates compared to 2D tasks (see Figure 1).

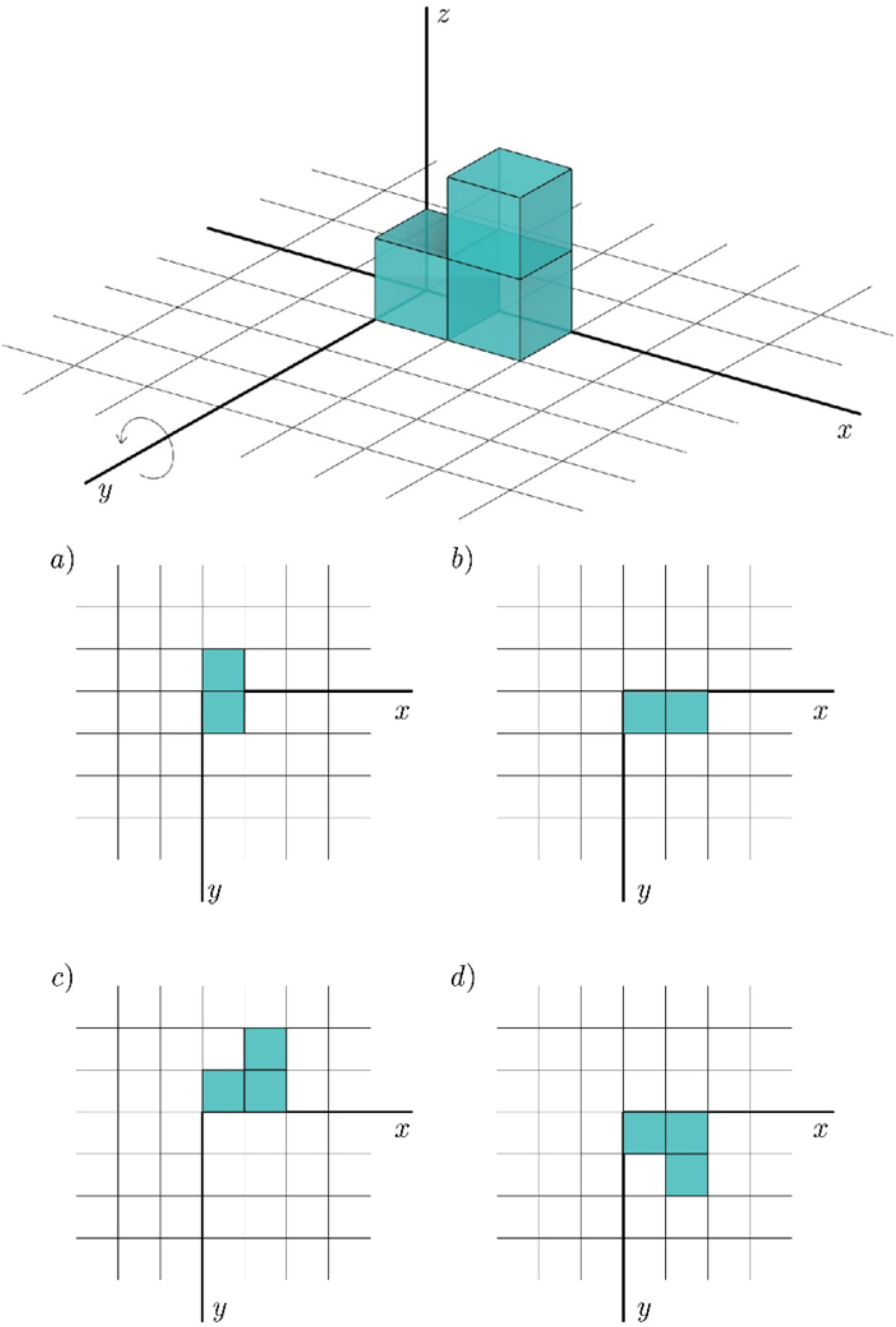

Figure 3: Task 13 – Identification of the projection of the object onto the *xy*-plane after rotating the object 270 degrees according to the indicated direction, 2021 (source: own drawing)

RQ4: How do deficiencies in conceptual knowledge contribute to students' errors in understanding tasks?

For Tasks 3, 5, 8 and 9, of which some of the subtasks were performed the least successfully, a more detailed analysis was undertaken of the possible causes of student errors due to insufficient conceptual knowledge. Our research confirmed that deficiencies in conceptual knowledge negatively affect student achievement.

In Subtasks 3.1 and 3.3 (see Figure 4), students determined the relative position of two straight lines in/on a cube based on a picture. Among the wrong answers, the following shortcomings often appeared in both tasks: instead of identifying the mutual positions of the given straight lines (parallel, intersecting, skew), the students used the formulation 'the straight lines intersect/do not intersect'. The most frequent error in Subtask 3.1 with two intersecting straight lines was the confusion between

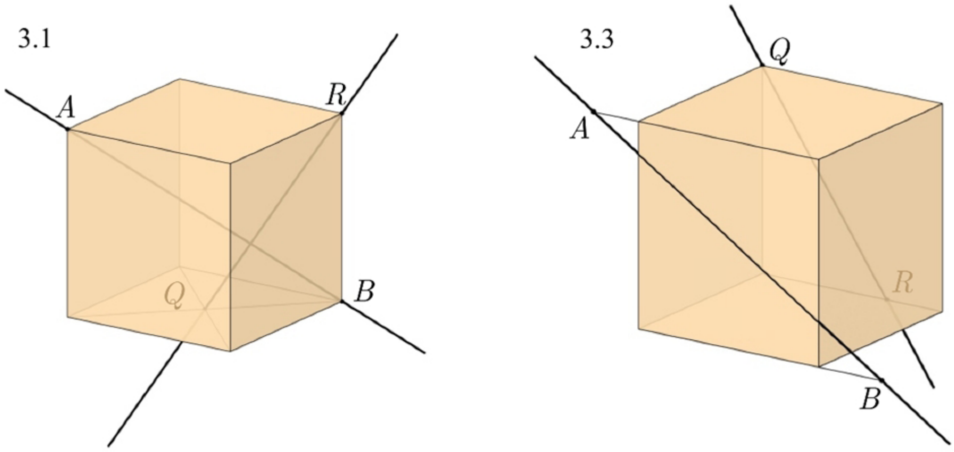

Figure 4: Subtask 3.1 and 3.3 – Identification of the relative position (i.e. parallel, intersecting, or skew) of two straight lines drawn in an auxiliary cube, 2021 (source: own drawing)

the metric relationship between the lines with a positional relationship: instead of intersecting lines, the students wrote about perpendicular straight lines. Other errors were mainly related to a lack of knowledge of the concept of skew and parallel straight lines, where, in both positions, the straight lines have an empty intersection, and it is necessary to distinguish whether the straight lines lie (for parallel ones) or do not lie (for skew ones) in the same plane. This was also indirectly confirmed by some respondents who stated in the notes to these tasks that they did not remember the necessary terms. Other studies have also identified that students have misconceptions about parallel straight lines (Biber et al., 2013; Youkap, 2021; Ulusoy, 2023) and perpendicular lines or segments (Duatepe-Paksu and Bayram, 2019; Ulusoy, 2023). This complies with Barut and Retnawati (2020), who have pointed to the problem of students' understanding of the concept of skew lines.

In each of the four subtasks of Task 5, the segment *AB* and its image *A'B'* under rotation around the given centre *S* by a certain oriented angle (the positions of *S* and *AB* are identical in all subtasks) were given. The situation was represented on a square grid. The task was closed. Students had to choose the appropriate size of the oriented angle from the offered options +90°, –90°, +60°, –60°, +45°, –45°. The correct answers were +90°, –90°, –60° and +45° in that order. We followed both the correct idea of the size of the angle of rotation, and the conceptual knowledge of rotation as such, especially the concept of the sense of rotation (plus/minus distinction). Students were the least successful in Subtasks 5.3 and 5.4. In the comments they mentioned a hesitation between 45° and 60°. However, they had greater difficulty with the plus/minus distinction, even though there was a hint in the assignment: 'plus corresponds to the sense of clockwise rotation'. If the absolute value was accepted as the correct answer (without the +/– distinction), only one answer would have been wrong in Subtasks 5.1 and 5.2, and the success rate would have increased noticeably in Subtasks 5.3 and 5.4 as well. Other researchers also draw attention to students' difficulties in determining the sense of rotation, for example (Clements et al., 1996; Clements and Burns, 2000). We consider the concept of the sense of rotation to be important for everyday life (e.g., opening a bottle, screwing, etc.).

Tasks with a low success rate also included Subtasks 8.3 and 9.1. In Tasks 8 and 9, students had to determine, without drawing pictures, the number of common points of two circles. Realising the relative position of the circles (Feng et al., 2014) was key to solving the tasks. Although this topic is not explicitly stated in the national curriculum (MEYS, 2005), it is included as a standard in the teaching of mathematics in lower secondary schools. The problem is usually visualised for students, and they solve the related problems using sketches. At the same time, they are led to derive the relationship between s (the distance between the centres of the given circles), r_1 and r_2 (the radii of the circles) for individual relative positions. In Task 8, the radii r_1, r_2 of both circles were given, and in the individual subtasks only the distance s was changed. In Task 9, only the radius of one circle was fixed, and the radius of the other and s varied. Many respondents found Tasks 8 and 9 difficult (as evidenced by their comments), especially because they were not allowed to use a picture, which is not usual in school teaching or in mathematics textbook tasks. Kambilombilo and Sakala (2015) also pointed out the difficulties with tasks beyond those common in textbooks.

Without a full understanding of a mathematical concept, the subsequent concept cannot be well understood (Aktaş and Ünlü, 2017; Hacisalihoğlu Karadeniz et al., 2017). Students need to have developed concepts such as a circle, intersection, point of tangency, etc. to understand the relative positions between two circles. For example, Hromadová et al. (2020) describe a misconception: 'the centre of a circle belongs to the circle'. This misconception can negatively affect the understanding of the relationship between two circles and the determination of the number of points they share in common. Some students in our test also stated that two circles have (exactly) three points in common.

Students with insufficient conceptual understanding rely on procedural understanding (Son, 2006). Tasks 8 and 9 would not be difficult without the prohibition of using an image. The low success rate points to difficulties in remembering and correctly visualising and comparing more data (three distances). In Subtasks 8.3 and 9.2, the circles shared one point in common (they touched internally). Through statistical analysis, it was found that the students' answers to these two subtasks are statistically dependent, i.e. that the students either solved both tasks or made mistakes in both. Subtasks 8.3 and 9.1 were among the tasks that were performed the least successfully, which is in line with our experience that the idea of circles touching internally and the related connections are the most difficult for students. The low success rate for Subtask 9.1, where the circles intersected at two points, was apparently caused by the use of symbolic notation in the assignment. This reason was also repeatedly mentioned by students in the comments. Selden and Selden (1995) pointed out that college students (including high school mathematics teachers) failed to consistently interpret informally written mathematical statements into equivalent formal statements. Similarly, Mutodi and Mosimege (2021: 1195) found that 'Misconceptions and poor conceptions in the interpretation of mathematical symbols result in students failing to link mathematical symbols and formulae with appropriate concepts'.

The above points to the fact that students' results in spatial ability may be related to students' conceptual knowledge. Other researchers also draw attention to this relationship in mathematics (e.g., Lowrie et al., 2019; Rittle-Johnson et al., 2019;) and also in other subjects, such as chemistry (Black, 2005).

Our findings show that conceptual misunderstandings contribute to students' errors in the performance of geometric tasks; however, we acknowledge that this is not the only possible explanation. In the case of 3D tasks, the lower success rates may also be due to the fact that less time is devoted to spatial geometry in the Czech mathematics curriculum. We cannot determine which factor contributes more to students' errors.

Limitations and Implications of the Study

Among the main limitations of our study is that it was conducted at a single institution and involved a relatively small sample of students, which may limit the generalisation of the results. Although the test was carefully designed to assess specific subcomponents of spatial ability, the classification of tasks into categories is partially based on expert judgement. Furthermore, some tasks may fall into multiple categories or may not be typical for a given category. We are also aware that the analysis should ideally include a qualitative component such as a more detailed analysis of students' written comments or additional comprehensive interviews. Future research may benefit from broader samples and additional qualitative data to further validate and expand our findings.

Despite these limitations, we believe that the results of our study offer important ideas for the design or modification of geometry courses at the university level. First, identifying specific subcomponents of spatial ability that present difficulties – particularly spatial visualisation – ensures that the instruction can include targeted practice with appropriate types of geometric problems. Second, examining students' conceptual misunderstandings provides meaningful feedback for improving the teaching of core geometry concepts, such as the relationships between lines and planes or between circles. Finally, because the study focuses on pre-service teachers, it has the potential to influence future teaching practice. These results can help improve the structure and content of university geometry courses to better prepare future mathematics teachers. This study may also serve as an inspiration for other researchers or educators aiming to improve spatial reasoning and conceptual understanding in geometry education.

CONCLUSION

The research presented in this paper provides insights into the spatial abilities of pre-service mathematics teachers in their first year of studies at the Faculty of Mathematics and Physics, Charles University, highlighting their varying proficiency across different geometric tasks.

Over three years of testing, it became evident that tasks involving spatial visualisation posed the most significant challenges, with students achieving a lower success rate compared to tasks requiring, for example, mental rotation. These findings underline the complexity of spatial visualisation tasks, which often require more difficult mental transformations than simple rotations. Furthermore, the research revealed a consistent trend: students performed better in planar geometric tasks compared to spatial ones, aligning with the broader educational focus on planar geometry within the Czech national curriculum. This outcome calls for enhanced training on spatial geometry, potentially improving educational outcomes in more complex 3D spatial reasoning tasks and for better support of the development of spatial abilities in pre-service mathematics teachers. The findings also emphasise the pivotal role of conceptual knowledge in understanding and solving geometric tasks. Throughout the research, it became clear that deficiencies in conceptual understanding significantly contributed to students' difficulties. For example, students struggled with tasks that required a deeper understanding of geometric properties and relationships. Improving conceptual knowledge can be considered a key strategy for enhancing students' overall performance in geometry. This is particularly important throughout the preparation of pre-service teachers, as they will be responsible for teaching these skills to future generations.

The findings are significant, as this is one of the first studies to use the same set of geometry tasks across three years to examine how first-year pre-service mathematics teachers perform in geometric problem solving. As for future research, the same group of students will be tested again at the end of their university studies. This will allow us to compare students' results at the beginning and end of their studies and to analyse whether the interventions provided through the university geometry course have been effective.

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Full research paper

ASSESSMENT OF INFORMATION AND COMMUNICATION COMPETENCE OF FUTURE TEACHERS BASED ON LABORATORY WORK IN NATURAL SCIENCES

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ABSTRACT

In the context of globalization and rapid advancement in information and communication technologies (ICT), ICT competence is crucial in professional training, including education. This study focuses on integrating ICT into the educational processes of future science teachers to enhance their ICT competence. The objective is to evaluate ICT's efficacy in laboratory work within natural sciences for developing ICT competence among prospective teachers.

The research methodology involved an experimental study at Zhetysu University with students in pedagogical physics, biology, and chemistry programs. Participants were divided into two groups: one followed a traditional pedagogical approach, and the other incorporated ICT into their lab work. Initial and final surveys measured the students' ICT competence levels.

The study's findings showed a significant improvement in ICT competence among students who used ICT in their studies, demonstrating the effectiveness of integrating modern technologies into education. The paper recommends that educational institutions incorporate ICT into their curricula and suggests directions for further research in this field.

KEYWORDS

Educational process, future teachers, information and communication competence, information and communication technologies, laboratory work, natural sciences

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Highlights

- *Students of pedagogy in natural sciences who used ICT in laboratory work reported significantly higher improvement in ICT competence.*
- *The improvement was indicated in operational, information and communication competencies, critical thinking and problem-solving, project management, ICT security and ethics.*
- *Using ICT tools in the educational process positively affects the formation of students' ICT competence.*

INTRODUCTION

Modern technology has become integral to learning and teaching in the rapidly evolving educational landscape. Modern technology has heralded a revolution in learning and teaching, fundamentally altering the education landscape. This work sets the stage for exploring modern technology's profound impact and versatile utility in reshaping education and embarks on a journey to explore modern technology's profound use and utility in shaping contemporary educational paradigms (Kumar et al., 2024). The use of ICT in the study of natural sciences will allow to show the fundamental unity of the laws of nature, to greatly increase students' interest in studying these natural disciplines, will intensify the learning process, ensuring a high level of results in the form of key competencies (Hladun, 2020). This becomes important in the context of natural sciences, where the complexity of the material and the need for its visualization and practical application require teachers not only to have in-depth knowledge of the subject, but also the ability to effectively use information and communication technologies to achieve educational goals.

This paper seeks to enhance the existing body of research by evaluating the effectiveness of integrating ICT in laboratory work within the context of natural sciences education. By investigating the influence of this integration on the information and communication competencies of future teachers, this study aims to address a gap in the current scholarly discourse regarding the practical application of ICT in educational environments. We begin by detailing the methodology underpinning our research, including the experimental design, participant selection, and data analysis techniques. Following this, we present the study's results, offering a comprehensive look at the observed enhancements in ICT competencies among the participants. The discussion then situates these findings within the broader scholarly discourse, underscoring their significance for the future of teacher education and the integration of ICT in educational curricula. The article concludes by summarising the key contributions of this research, acknowledging its limitations, and proposing directions for future investigations in the field of ICT in education.

ICT Competencies in the Education of Future Teachers

In 2018, the OECD had already advised that education has a vital role to play in developing the knowledge, skills, attitudes and values that enable people to contribute to and benefit from an inclusive and sustainable future. Learning to form clear and purposeful goals, work with others with different perspectives, find untapped opportunities and identify multiple solutions to big problems will be essential in the coming years. Education needs to aim to do more than prepare young people for the world of work; it needs to equip students with the skills they need to become active, responsible and engaged citizens (OECD, 2018).
For academic institutions to be successful, their model of educational and organizational democratic accountability must be restructured to act rapidly and precisely, create fresh concepts effectively, and enable adaptable and respectful facilities. This attitude transformation toward an 'entrepreneurial mindset' must begin (Stolze, A., Sailer, K., & Gillig, H., 2018). In these conditions, a Higher Education is faced with the task of preparing specialists for professional activity, considering the active use of digital technology.
It should be noted that economically developed and competitive countries invest the most—both materially and financially—in the development of education. Today, universities are experiencing the profound effects of digital transformation, which has not only introduced new challenges but also intensified existing ones. They are increasingly forced to compete for students with emerging players in the digital education market. As noted by the Minister of Science and Higher Education of the Republic of Kazakhstan, Sayasat Nurbek, in an interview with the Astana Times (Ualikhanova, 2023), 'Digital technologies have become an integral part of the modern world and have great potential for the successful implementation of higher education,' which requires 'a transition from traditional educational models to active teaching methods' for the successful digital transformation of higher education. According to the Resolution of the Government of the Republic of Kazakhstan (2018), the improvement of digital competencies of citizens will be continued through the system of training, retraining and obtaining micro qualifications in the field of ICT. Digital competencies will become a mandatory element of all professional standards. Developing the ICT competence of future teachers is therefore essential—not only for effective teaching but also for preparing students to thrive in a knowledge-based, technology-driven society. According to Ghavifekr and Rosdy (2015), ICT competence today goes far beyond the basic use of computer programs. It refers to a teacher's ability to integrate technological tools into the educational process in ways that foster students' critical thinking, creativity, and problem-solving skills.
According by the Sayasat Nurbek, in an interview with the Astana Times (Ualikhanova, 2023), in Kazakhstan, where the educational system is transitioning toward digitalisation, teachers are increasingly required to adopt new pedagogical approaches rooted in ICT. Consequently, more attention is now being paid to developing ICT competence in future educators. This competence is understood as a set of knowledge, skills, and personal qualities that enable the effective use of information and communication technologies to perform diverse tasks, pursue training and self-education, and interact successfully in both social and professional contexts. This competence is particularly vital in teacher preparation, as future educators must not only consume digital content but also become active participants in the information society—capable of creating, processing, and sharing knowledge using modern ICT. Sergeeva et al. (2024) reported that pre-service teachers' ICT competency beliefs can help identify factors influencing their attitudes and intentions to use technology in their future classrooms. By understanding these factors, teacher education programs can provide appropriate support and training to increase prospective teachers' confidence and motivation to use ICT in their teaching practice. In addition, measuring pre-service teachers' ICT competency beliefs can provide insight into the effectiveness of current ICT courses and training programs in preparing them for their future roles as educators.
A study was previously conducted at Zhetysu University, with the participation of 20 teachers and 100 students at the Higher School of Natural Sciences, it was revealed that teachers master basic computer skills and can effectively use ICT in the educational process, including working with multimedia equipment and using ICT to teach specialised disciplines and communicate with students. These findings highlight the need for further development of ICT competence among the teaching staff to improve the quality of the educational process. The students, in turn, positively assessed the use of ICT by teachers, stressing that it contributes to improving the effectiveness of learning. However, they also pointed out the importance of finding the optimal balance between virtual and personal communication. The results of this prior research were presented at an international conference and published in a scientific article (Kabdualiyev et al., 2023).
In the ever-evolving digital era, the role of information and communication technology in interactive learning has ushered in a new chapter in education. This transformation has not only impacted how we learn and teach but has also changed our perspective on education itself. From digital learning platforms that provide unlimited access to knowledge, to the use of multimedia that enhances student understanding, ICT has brought about a revolution in education that is more inclusive and dynamic (Anastasopoulou et al., 2024). This shift enables

teachers to create more engaging lessons that can cater to diverse learning styles, making complex concepts easier to understand. Moreover, ICT has introduced a wide array of educational software and applications designed to reinforce learning through interactive exercises and immediate feedback (Anastasopoulou et al., 2024).

Alférez-Pastor et al. (2023) claim that future teachers must be trained as digitally competent individuals to eliminate the barrier to digital tools in education. Teachers are a key element in technological transformation since their attitude towards educational technologies is a determining factor in responding to educational innovation and technological advances in today's society. Tomczyk et al. (2023) stated that measuring digital competence among future teachers is being carried out worldwide in various ways. Despite the different typologies, there is currently no standardised way of measuring ICT skills in the teaching and learning dimensions. Silva-Quiroz and Morales-Morgado (2022) confirmed that digital competence should be integrated into the curriculum of university programs, especially pedagogy so that students use technology for their academic and personal development. Huamán-Romaní et al. (2022) stated that universities at the national level are training professionals with professional training competence where basic knowledge of the subject predominates, both in the theoretical and practical part, as well as training in ICT.

In a similar study, Bogachkov, Ukhan and Yutsevych (2019) explain the concept of competency level as an index characterizing the probability of successfully performing a task (at a given level) from a defined set of tasks in a specific context by a particular performer. They define information and communication competencies as a set of knowledge, skills, and abilities developed through learning and self-learning in computer science and information technology. These competencies include the ability to perform professional activities using information technology. Specifically, they describe this as the ability to work with information (collection, search, transfer, and analysis); to model and design one's own professional activities; to model and design the work of a team; to navigate the organizational environment using modern ICT; and to use modern ICT tools in professional activities to enhance labour productivity.

These definitions emphasise, in our opinion, a crucial aspect of updating the ICT competence of students for their future professional activities. In the context of the Kazakh educational system, information and communication technologies have become essential tools for improving the quality of education and developing competence among students and teachers. Kopeyev et al. (2020) raised questions about students who lack motivation since they already know the subject being studied. These are students with a good level of knowledge. In contrast, others have less motivation due to a lack of understanding of the material being studied, a lack of basic knowledge, and an insufficient level of learning outcomes in the field of computer science.

Many teachers and methodologists are engaged in methodological issues of integrating ICT tools into educational practice (Alemu, 2015; Lawrence & Tar, 2018; Sutherland et al., 2004). These authors emphasise the importance of using interactive teaching methods in a virtual environment, pay attention to the didactic value of working with computer models, and emphasise the need to increase their functionality, activating the activities of students.

Effective use of computers and technology in teaching is possible with teachers who are knowledgeable and well-trained in using technology. In today's world, where education affects technology and technology affects education, a teaching approach that is not reflected in the educational environment and lacks technology negatively affects success. For this reason, using computers and technology has become compulsory in today's education. In the light of the findings, various suggestions need to be made. In this direction, first of all, teacher trainers should educate, inform and raise awareness of pre-service teachers about digital literacy and technology usage skills, which are considered to be among the requirements of the 21st century and whose importance is expressed in many national and international studies in terms of the educational process (Nurzhanova et al., 2023).

Preparation of students as subjects of professional and pedagogical activity remains one of the current problems, as modern Kazakhstan educational system is in a stage of dynamic renewal caused by, on the one hand, the process of reforming society as a whole, and on the other hand, the logic of the educational system development. Thus, it is important to develop new approaches, new forms of learning (Zhaukumova et al., 2021). The practice-oriented content of the educational material allows bringing teaching closer to specific situations of professional activity, the chosen specialty, to form the life experience of students, thus increasing the level of knowledge and skills, cognitive interest, and, as a result, to form the level of professional competence of students (Manashova et al., 2021). Such training enables students to master modern educational technologies and to apply them in professional activities. In addition, it fosters adaptability to the rapidly changing demands of the information society.

Matviyevskaya et al. (2019) observe that dynamic changes in the modern world dictate the need to find new approaches to the theory and practice of forming ICT competence in all areas of human activity, especially in forming ICT competence of future teachers. Informatization of education is declared as one of the priority directions of the state policy in the field of education. ICT plays a unique role in improving the quality of education. It simplifies the integration of the national education system into the world and facilitates access to international sources of information in education, science and culture. The need to form ICT for future teachers relates to the changing structure of educational information interaction between teachers and pupils.

Klara and Alamash (2023) suggest that digital technologies make it possible to develop existing methods for monitoring and assessing the level of knowledge of future teachers and create new, more advanced, modern methods. At the same time, by analysing a lot of information about students and their activity in the digital environment, the university teacher can provide him with sufficient assistance, opening opportunities for independent work for future teachers in the digital environment.

Based on the research of Kormakova et al. (2021) and Wong and Daud (2018), we propose the following key ICT competencies depicted in Figure 1. These skills include operational, information, communication, critical thinking, problem-solving, project management, and ICT security and ethics.

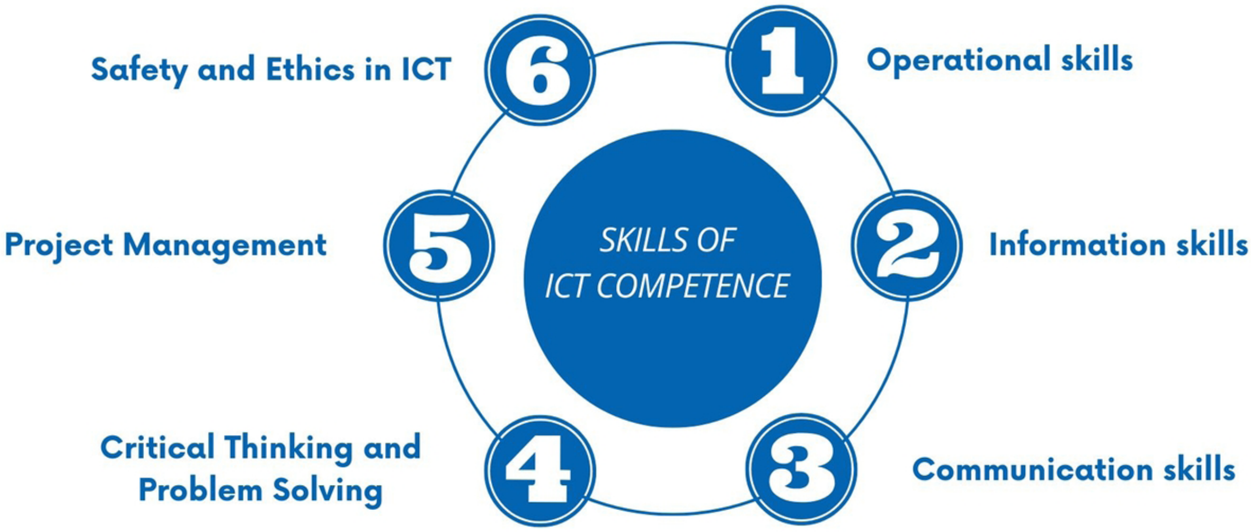


Figure 1: Development of ICT competence through laboratory work (Source: Accepted from Kormakova et al.,2021; Wong & Daud, 2018)

It is of extremely high priority for prospective teachers to establish a rich set of information and communication technologies to advance their professional competence. Every single one of these skills is a part of establishing extensive ICT competence, which is the core part of the professional development of a modern teacher. Teachers who possess these skills become more effective and are allowed to implement technology to transform the educational process and the growth of student motivation to study. Table 1 offers a detailed illustration of every single one of these skills, showing their significance for the competent application of ICT in modern lessons and the efficient implementation of technology into the professional life of teachers.

ICT Competence	Use in laboratory work	Description
Operational skills	Basics of working with a text editor	Learning the functions of a text editor, such as formatting text, inserting images, and creating tables
	Mastering the simulation program	Introduction to software for creating and analysing models
Information skills	Search and evaluation of scientific sources	Development of search strategies in scientific databases and assessment of the reliability of the information found
	Data Analysis using Excel	Using Excel to collect, process, and visualise data
Communication skills	Maintaining a scientific blog	Creating and maintaining a blog to discuss the results of laboratory work.
	Online conference on the results of projects	Organisation and holding of online presentations of projects.
Critical thinking and problem-solving	Laboratory for virtual experiments	Application of theoretical knowledge to solve practical problems.
	Case study on problem-solving	Analysis of real cases and development of solutions
Project management	Planning and management of an ICT project	Development of a project plan, including the allocation of tasks
Security and ethics in ICT	Digital Security Course	Studying the principles of data protection and safe use of the Internet
	Ethical dilemmas in ICT	Discussion and analysis of ethical dilemmas

Table 1: Development of ICT competence in laboratory work (Source: Accepted from Kormakova et al.,2021; Wong & Daud, 2018)

Asare et al. (2023) argues that choosing between traditional and virtual laboratories in science education should be based on carefully considering the educational goals and available resources. Traditional laboratories offer a rich and immersive hands-on experience, fostering a deeper connection to science, but can be resource intensive. Virtual laboratories, while providing accessibility and cost-efficiency, may lack sensory engagement and present technological challenges. A balanced approach, combining both traditional and virtual laboratories, can provide a comprehensive science education that leverages the strengths of each approach, catering to a broader range of student's needs and circumstances.

According to Potkonjak et al. (2016), concepts such as distance learning and open universities are now becoming more widely used for teaching and learning within education. However, due to the nature of the subject domain, the teaching of Science, Technology, and Engineering are still relatively behind when using new technological approaches (particularly for online distance learning). The reason for this discrepancy lies in the fact that these fields often require laboratory exercises to provide effective skill acquisition and hands-on experience. Often it is difficult to make these laboratories accessible for online access. Either the real lab needs to be enabled for remote access or it needs to be replicated as a fully software-based virtual lab.

Type of virtual laboratory	Description	Application
Interactive simulations	Virtual laboratories that allow students to interact with experimental parameters and observe changes in real-time.	The study of complex scientific concepts such as quantum mechanics, genetic mutations, and chemical reactions.
Virtual laboratory stands	Platforms offering virtual versions of real laboratory stands for conducting experiments using standard equipment and reagents.	The study of methods of working with equipment, the safety of laboratory research and techniques for performing experiments.
Process modelling	Tools for creating and testing models of biological, chemical, or physical processes through computer modelling.	Modelling of ecological systems, chemical reactions, and physical phenomena (fluid flow, particle dynamics).
3D labs and VR	The use of virtual reality technologies to create immersive laboratory environments that allow to interact with equipment and conduct experiments in 3D space.	Conducting complex or dangerous experiments that are difficult to implement in a real laboratory.
Online courses with laboratory work	Courses in natural sciences, including virtual laboratory work, providing both theoretical and practical skills.	Providing comprehensive training through videos, interactive tasks and simulations.

Table 2: Types of virtual laboratory work (Source: Accepted from Potkonjak et al., 2016).

These examples show how utilizing traditional laboratory and virtual laboratory work, students can acquire ICT competence while mastering contemporary ICT and acquiring priceless skills for their future professional activities.

Based on the study by Byukusenge, Nsanganwimana and Tarmo (2022), conceptual understanding is the learning outcome that is enhanced most when using virtual labs. Virtual labs improve students' motivation, self-efficacy, and attitudes toward learning biology topics. Virtual laboratories deserve the attention of researchers, teachers, and instructional designers due to their appealing nature as a means of actively involving students in safer and more cost-effective scientific inquiry. The effectiveness of virtual labs, like any other instructional tool, may be significantly influenced by how they are used in the classroom. Moreover, according to a study by Benda, Pavlik and Masner (2019), the virtual laboratory or learning environment applied to a web interface is convenient even for students with mental disabilities. The acquisition of information and communication competence using ICT in laboratory work contributes not only to the increase in the level of education but also to the ability of students to successfully use new technologies in the future, in which the possession of ICT skills is one of the crucial factors.

Hypotheses

Based on the objectives of the study and the findings of the literature review, a series of hypotheses were formulated to assess the influence of ICT integration in laboratory work on the development of students' digital competencies. Each hypothesis addresses a specific area of competence, including operational skills, information skills, communication skills, critical thinking and problem-solving abilities, project management skills, digital security awareness, and overall ICT competence.

Hypothesis 1: the inclusion of tasks in laboratory work on the **use of basic ICT tools**, such as word processors (Microsoft Word, Google Docs), spreadsheets (Excel, Google Sheets), and presentation software (PowerPoint, Google Slides), **does not lead** to a significant **improvement in students' operational skills**.

Hypothesis 2: Encouraging students to **use search engines** (Google, Yandex) and educational resources on the Internet (Coursera) to collect and analyse information within the framework of laboratory work does not contribute to the development of their **information skills**.

Hypothesis 3: Regular completion of tasks requiring **information exchange and collaboration in groups** (Google Drive) and messengers (WhatsApp, Telegram) **does not improve** students' **communication skills** in a digital environment.

Hypothesis 4: Involving students in solving practical problems and projects **using online calculators and simple data visualisation programs** (Google Sheets with a chart function, Canva for creating infographics) does not contribute to the development of their **critical thinking and problem-solving skills**.

Hypothesis 5: the use of simple **project and task management tools** (Google Calendar) in laboratory work does not help students develop **skills in planning and organising** work on projects.

Hypothesis 6: the inclusion in the educational process of elements aimed at teaching the **basics of digital security** (Norton Security) **and ethics** (etiquette of communication on the Internet, conscious use of content) does not help to **raise students' awareness** of the importance of these aspects in the digital environment.

Hypothesis 7: the **use of ICT tools** does not have a significant impact on the ICT competence of students.

MATERIALS AND METHODS

To analyse the materials and results of the study, several methods were employed. General scientific methods included a comparative analysis of pedagogical and scientific-methodical literature related to the research topic. Sociological research methods involved conducting surveys among prospective physics, chemistry, and biology teachers, followed by comparison, classification, and analysis of the collected data. Additionally, empirical research methods were applied, such as implementing a pedagogical experiment, using statistical techniques, and processing and analysing the obtained results. The study examined the impact of ICT integration in laboratory work on the formation of ICT competence among students enrolled in three educational programs: biology, chemistry, and physics. Participants included third- and fourth-year students at Zhetysu University.

Participants

A survey was conducted among students to assess their information and communication competence. The distribution of participants was out through random assignment to ensure comparability and minimize bias.

Biology (N = 48): The cohort was divided into control and experimental groups, each with 24 students.

Chemistry (N = 36): Participants were equally split, with 18 students in each group.

Physics (N = 31): The experimental group had 16 students, while the control group consisted of 15 students.

Data Collection

A structured data collection process was developed to ensure the through and systematic gathering of information necessary for the study. Data collection includes eight consecutive stages, each involving specific methods and tools tailored to the particular tasks at hand. The steps of data collection and analysis methods are shown in Figure 2.

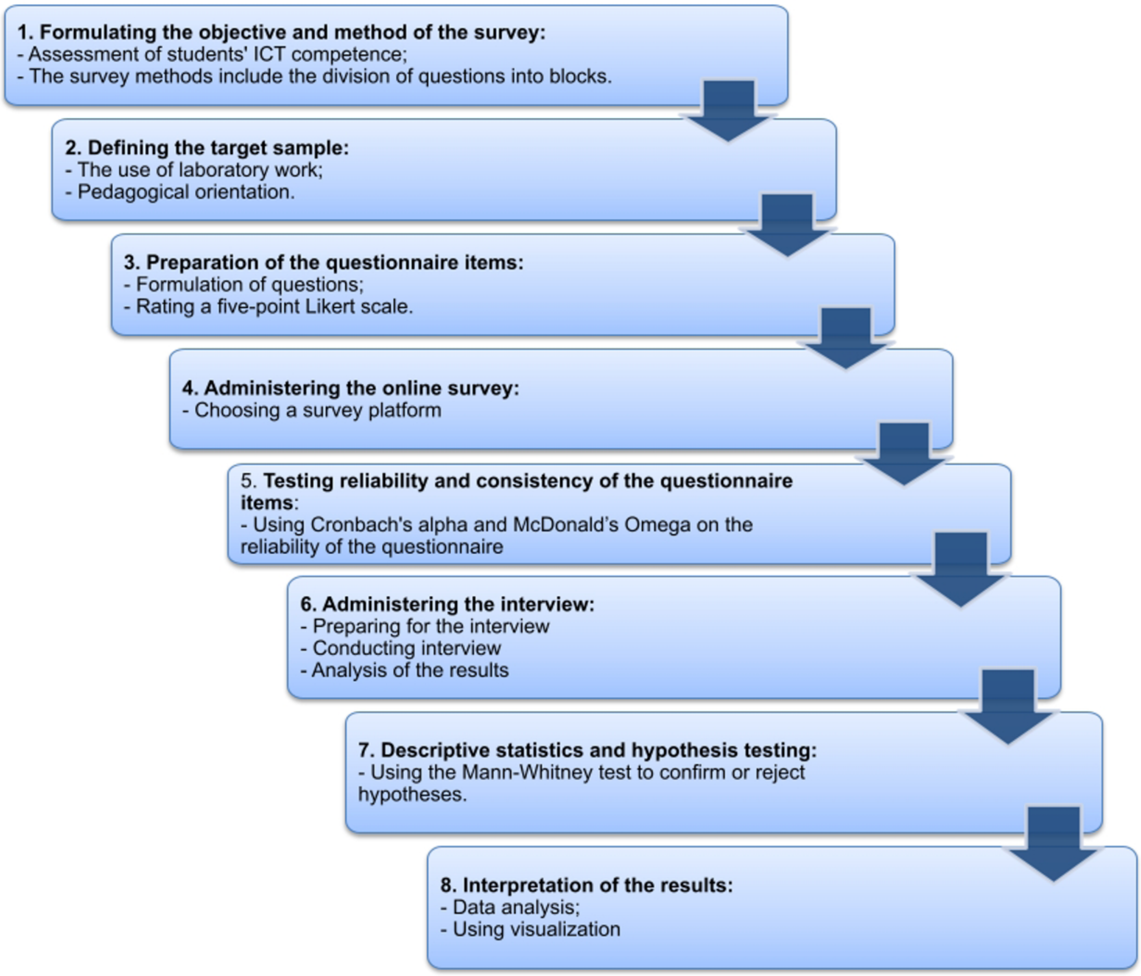


Figure 2: Stages of data collection and analysis methods (Source: own)

As part of research conducted at the Higher School of Natural Sciences of Zhetysu University, students of the educational program for pedagogical physics, biology, and chemistry were involved in the experiment. The purpose of the experiment was to assess the effect of the use of information and communication technologies (ICT) on the development of their information and communication competence, emphasizing the use of ICT during laboratory work rather than in the general learning process.

The participants were divided into two groups: the control group was trained according to the traditional methodology, while the experimental group actively used ICT during laboratory work. All participants' initial level of ICT competence was assessed as below average through a survey conducted before the experiment. This survey revealed limited knowledge of ICT and insufficient use of technology in the educational process.

During the experiment, the experimental group students used various ICTs, including specialised data analysis software, online collaboration platforms, digital tools for visualising scientific concepts and interactive applications for conducting virtual laboratory experiments. This approach allowed students not only to gain a deeper understanding of natural sciences, but also to significantly improve their information and communication skills. At the end of the experimental period, a repeated survey was conducted to test the changes in ICT competence.

Questionnaire Design

The study design provided for conducting a survey among all participants, as well as subsequent interviews with half of them, which allowed us to obtain both quantitative and qualitative data on their ICT competencies.

Based on the work of Caluza et al. (2017), we compiled 36 close-ended questions divided into six blocks representing the following information and communication competencies: operating skills, information skills, communication skills, critical thinking and problem-solving skills, project management, and security and ethics in ICT skills described in Table 1.

The survey questions are presented in Appendix. We employed 5-point Likert scale measuring respondents' skills ranging from '1 - very bad' to '5 – very good'. The questionnaire was designed in Kazakh and distributed online as a Google form between January 15 and February 3, 2024.

Interviews

In addition to the questionnaire, interviews were conducted with 57 students, which made it possible to explore their views and experiences of using ICT in more depth. The interview consisted of a series of open-ended questions aimed at clarifying the practical application of ICT in the educational and daily activities of students. The blocks of questions concerned all six skills. The interview questions are presented in Appendix. This approach allowed not only to confirm the data obtained during the survey but also to expand the understanding of how students perceive their competence and what factors, in their opinion, contribute to or hinder its development.

RESULTS

We analysed the results in two levels. First, we present results of testing the influence of using various laboratory work elements on improving particular ICT competencies. Second, we analysed the results by student specialties and groups.

Survey Tool Reliability and Variance Analysis

To assess the internal consistency of the questionnaire, two reliability coefficients were used: the Cronbach's Alpha coefficient and the McDonald's Omega coefficient. The choice of a dual approach is due to the fact that Cronbach's Alpha is traditionally the most common reliability indicator, which is based on the assumption of equal loads of all scale elements on the measured factor. Additionally, the McDonald's Omega was calculated, which is a more modern and accurate reliability indicator that takes into account possible differences in the contribution of individual issues to the overall result. The calculation of McDonald's Omega allows us to obtain a more accurate assessment of the internal consistency of the scales, especially in the presence of varying degrees of factor load between individual elements of the questionnaire. Thus, the use of both coefficients provides a comprehensive and reasonable assessment of the reliability of the instrument.

The resulting Cronbach's alpha value was 0.89, which indicates a high internal consistency of the scale and reliability of the instrument used. According to generally accepted criteria, Cronbach's alpha values above 0.7 are considered acceptable, and values above 0.8 indicate high reliability, α is found to be an appropriate index of equivalence and, except for very short tests, of the first-factor concentration in the test. (Cronbach, 1951). This suggests that the questionnaire has a sufficient degree of consistency for subsequent data analysis.

To identify statistically significant differences between the factors, a single-factor analysis of variance (ANOVA) was performed (Table 3).

The source of the variation	*SS*	*df*	*MS*	*F*	*P*-Value	*F* critical
Lines	421.38	114.00	3.70	9.67	5.21E-139	1.23
Columns	53.33	35.00	1.52	3.99	4.00E-14	1.43
Error rate	1524.82	3990.00	0.38			
Total	1999.53					
Cronbach's Alpha	**0.89**					

Table 3: the ANOVA results (Source: own calculation)

The analysis of the variance showed that the differences between the groups (lines) are statistically significant: $F(114, 3990) = 9.67$, $p < 0.001$. This indicates that there are significant differences in the responses of respondents between different groups of participants or variables, which indicates the influence of experimental factors on the results of the study. Similarly, the differences between the columns (within the groups) also turned out to be significant: $F(35, 3990) = 3.99$, $p < 0.001$, which emphasizes the importance of individual factors in the overall model. The residual variance (error) was 1524.82 with $MS = 0.38$, which reflects the level of random variability of the data. The total sum of squares (SS) for all factors was 1999.53, which confirms a fairly wide range of variability of the studied data. Thus, the high level of significance of the factors and the high reliability of the tool confirm that the questionnaire has a sufficient degree of consistency.

The internal consistency of each block of the questionnaire was evaluated using McDonald's Omega coefficient. The results are presented in Table 4. Based on commonly accepted standards, a McDonald's Omega value greater than 0.7 indicates acceptable reliability, while values exceeding 0.8 reflect very good internal consistency (McDonald, 1999). Most blocks demonstrated very good or good reliability, with Omega values ranging from 0.77 to 0.83, confirming the high internal consistency of the scales. Only the Communication block showed an acceptable reliability level (Omega = 0.67), which still meets the minimum threshold for social science research instruments. The lower Omega value observed for the Communication block may be due to the broader and more heterogeneous nature of the skills assessed within this dimension.

Block	Name of Block	Number of question	McDonald's Omega	Result
1	Operating	6	0.83	Very good reliability
2	Information	6	0.81	Very good reliability
3	Communication	6	0.67	Acceptable reliability
4	Critical thinking and problem-solving	6	0.79	Good reliability
5	Project management	6	0.79	Good reliability
6	Security and ethics in ICT	6	0.77	Good reliability

Table 4: Results of McDonald's Omega (Source: own calculation)

The analysis of internal consistency, conducted using both Cronbach's alpha and McDonald's Omega, confirmed the reliability of the developed questionnaire. The obtained results indicate that the instrument consistently measures the intended constructs and can be regarded as a reliable tool for subsequent research and educational applications.

Hypotheses Testing

The Mann-Whitney criterion was used for independent samples to test the hypotheses since the sample did not correspond to the assumption of a normal distribution and was not a random sample from the entire population. The Mann-Whitney test (or U-test) is a nonparametric method used to test the differences between two independent samples. It evaluates whether there are statistically significant differences between the medians of the two groups, and is useful when the data does not correspond to a normal distribution (Iuliano and Franzese, 2019).

Interpretation of Results of the Mann-Whitney Test

The *U-statistic* is a numeric value that reflects the difference in the rank sums of the two samples. It serves as the basis for calculating other statistical indicators. In studies comparing two groups before and after an experiment, *U-statistic* is an essential tool for assessing the differences between the distributions of responses in these groups.

The *p-value* reflects the probability of obtaining an observed or more extreme *U-statistic* if there are no real differences between the groups (the null hypothesis is correct). In scientific research, it is considered that the difference is statistically significant if the p-value does not exceed 0.05.

The *Z-value* is a standardized value that shows how far the *U-statistic* deviates from the average for a particular sample. The *Z-value* converts the *U-statistic* to a standard scale, which makes it possible to compare the results of various studies.

The *R-value* is an indicator that characterizes the strength of the effect, reflecting the degree of differences between the groups. It is calculated as the ratio of the *Z-value* to the root of the total number of observations. The *R-value* can take values from -1 to 1. The closer it is to -1 or 1, the stronger the effect. Values close to 0 indicate slight differences between the groups (Sheskin, 2000).

Results of the Mann-Whitney U-Test of ICT Competence Skills

Table 4 presents the Mann-Whitney U-Test results for data before and after the surveys. The study showed statistically significant differences between the control and experimental groups before and after the experiment for each value of ICT competence skills. These results indicate the positive impact of the use of ICT tools in the laboratory works on improving the ICT competence of students, which showed a significant improvement in ICT competence among the students of the experimental group. It was noted that students not only improved their technical skills in dealing with ICT, but also developed the ability to think critically, analyse and interpret data, as well as improved their communication skills in a digital environment. The diagram shows the assessment results of information and communication competencies before and after the experiment, including the control and experimental groups.

ICT Competence skills	Group	*U*-statistic	*P*-value	*Z*-value	*R*-value	Result
Operating	Control Group	1400.5	0.19	-1.27	-0.12	Accepted
	Experimental Group	0.0	8.40e-21	-9.29	-0.86	Rejected
Information	Control Group	1323.0	0.108	-1.57	-0.15	Accepted
	Experimental Group	0.0	1.09e-20	-9.25	-0.86	Rejected
Communication	Control Group	1487.0	0.433	-0.78	-0.073	Accepted
	Experimental Group	58.0	2.38e-19	-8.97	-0.83	Rejected
Critical thinking and problem-solving	Control Group	1473.0	0.387	-0.86	-0.08	Accepted
	Experimental Group	0.0	2.67e-20	-9.21	-0.86	Rejected
Project management	Control Group	1395.0	0.057	-1.85	-0.17	Accepted
	Experimental Group	0.0	4.74e-20	-9.12	-0.86	Rejected
Security and ethics in ICT	Control Group	1354.5	0.033	-2.07	-0.19	Rejected
	Experimental Group	0.0	4.85e-20	-9.12	-0.86	Rejected

Table 5: The results of the Mann-Whitney U-Test, alpha 0.05 (Source: own calculation)

Table 5 shows significant differences between the control and experimental groups in various ICT competencies. P-value values of less than 0.05 indicate a rejection of the null hypothesis, which indicates the presence of significant differences. The results on the competence 'Security and ethics in the field of ICT' in the control group are particularly interesting, where the p-value was 0.033, which is close to the threshold value. This may indicate that students from the control group, in particular, students of the educational program in pedagogical physics, showed better results in issues related to the safety and ethics of using ICT. This conclusion is supported by a diagram showing that students from this program improved their results in this competence after the experiment (Figure 5).

For all ICT competence skills (operational skills, information skills, communication skills, critical thinking and problem solving, project management, safety and ethics in ICT), extremely low p-values were observed in the experimental groups (from 8.40E−21 to 4.85E−20), indicating statistically significant differences between the control group and experimental groups. The values of the *Z-statistic* for the experimental groups range from -8.97 to -9.29, which indicates significant deviations. The *R-values* for the experimental groups are -0.86 and close to this, which indicates a strong negative correlation. The study results demonstrate a statistically significant improvement in the ICT competence of students in the experimental groups compared with the control groups in almost all the crucial skills considered. Thus, the conducted research confirms the importance and necessity of integrating ICT into the educational process to improve the skills of future specialists in the field of pedagogical sciences. A more detailed view of the results by student specialties is presented in the following text.

Experimental Results: Biology Program

Within the framework of the biology educational program, emphasis was placed on the use of ICT to study biological data and conduct virtual experiments in the field of molecular biology, genetics and ecology. Students had the opportunity to work with genome databases, conduct virtual laboratory studies and use specialised software to analyse environmental data. This allowed them not only to improve their information skills but also to develop an understanding of modern research methods in biology.

Figure 3 shows the results of evaluating the educational program's information and communication competence for pedagogical biology students before and after participating in an experiment to integrate information and communication technologies into the laboratory works. ICT competence was assessed in six essential skills: operational skills, information skills, communication skills, critical thinking and problem-solving, project management and ICT security, and ethics.

Operational skills: the experimental group showed an increase from 2.3 to 4.2, which indicates a significant improvement in the ability to use ICT tools and resources.

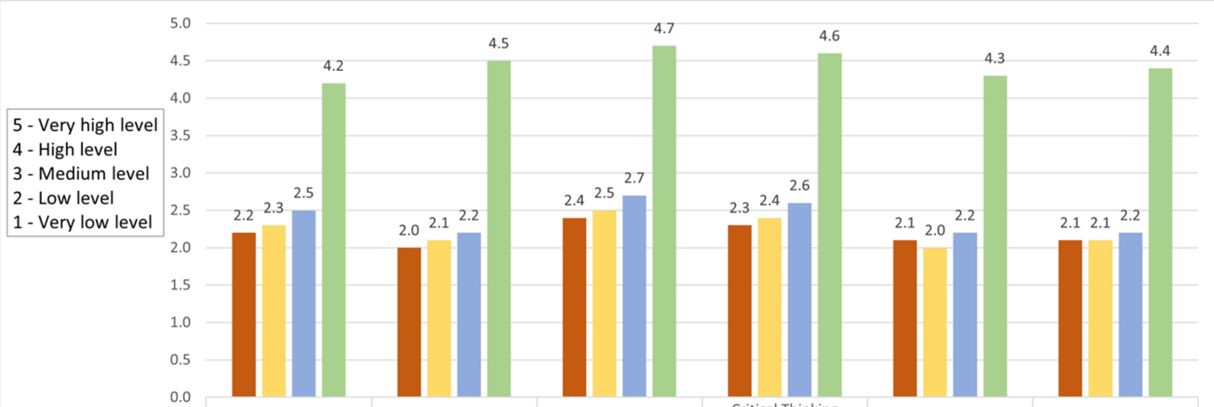
Information skills: the increase from 2.1 to 4.5 indicates that students have become much better at searching and processing information using ICT.

Communication skills: Grades increased from 2.5 to 4.7, reflecting an improvement in students' ability to share information and interact in the digital space.

Critical Thinking and Problem-solving: the results show an improvement from 2.4 to 4.6, which is one of the most significant gains and highlights the strengthening of analytical abilities and problem-solving skills.

Project management: Here, the experimental group's performance improved from 2.0 to 4.3, noting progress in project planning, organisation and control.

ICT security and ethics: an improvement from 2.1 to 4.4 indicates a higher level of understanding and application of the principles of security and ethics in the field of ICT.



	Operational	Information	Communication	Critical Thinking and Problem Solving	Project Management	ICT Security and Ethics
Before the Experiment (Control Group)	2.2	2.0	2.4	2.3	2.1	2.1
Before the Experiment (Experimental Group)	2.3	2.1	2.5	2.4	2.0	2.1
After the Experiment (Control Group)	2.5	2.2	2.7	2.6	2.2	2.2
After the Experiment (Experimental Group)	4.2	4.5	4.7	4.6	4.3	4.4

Figure 3: Diagram of the Assessment Results of ICT Competence of Students in the Educational Program for Pedagogical Biology (Source: own)

Experimental Results: Chemistry Program

Students of the educational program for pedagogical chemistry used ICT to simulate chemical reactions, study the structure of molecules and conduct virtual chemical experiments. Using digital tools and software to visualise chemical processes has facilitated the understanding of complex concepts and contributed to developing critical thinking. Virtual laboratories allowed students to experiment with various chemicals safely and study their properties and reactions, which contributed to the deepening of knowledge in the field of chemistry.

Figure 4 shows the results of assessing the information and communication competence of students of the educational program for pedagogical chemistry before and after the experiment. The experiment aimed to assess the impact of information and communication technologies in laboratory work. The data is grouped by the six essential skills.

Operational skills: the student's performance in the experimental group improved from 2.2 to 4.4, indicating a significant development of skills directly using ICT.

Information skills: the improvement from 2.1 to 4.6 reflects the growth of students' skills in finding, analysing and critically evaluating information.

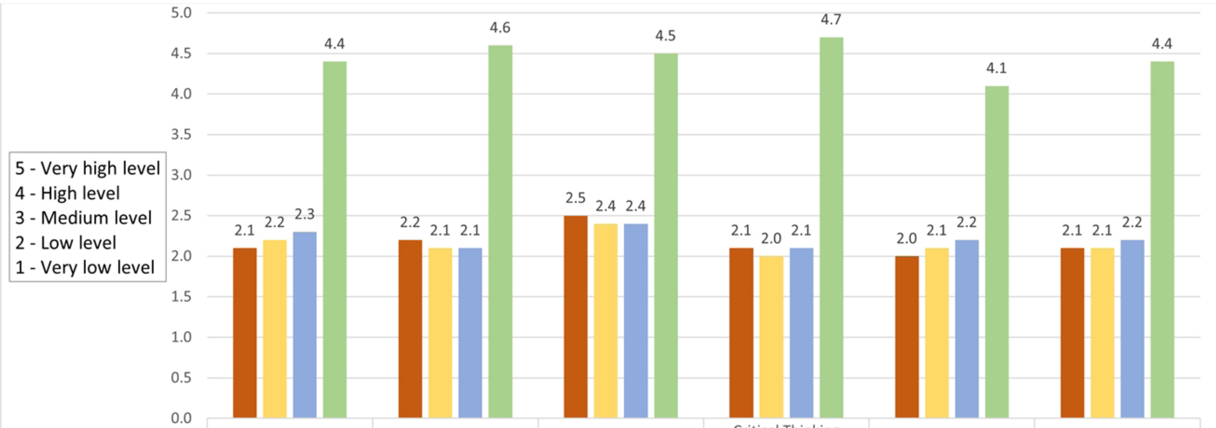
Communication skills: an increase from 2.4 to 4.5 indicates an improvement in students' ability to communicate and interact effectively.

Critical Thinking and Problem-solving: the score increased from 2.0 to 4.7, which is a significant improvement in students' ability to analyse situations and make informed decisions.

Project management: the increase from 2.1 to 4.1 indicates an improvement in skills in planning, organising and managing projects.

Project management: the increase from 2.1 to 4.1 indicates that students have significantly improved their ability to organize their work and manage time and resources effectively.

ICT Security and Ethics: the improvement from 2.1 to 4.4 demonstrates students' increased understanding of security and ethical aspects in the field of ICT.



	Operational	Information	Communication	Critical Thinking and Problem Solving	Project Management	ICT Security and Ethics
Before the Experiment (Control Group)	2.1	2.2	2.5	2.1	2.0	2.1
Before the Experiment (Experimental Group)	2.2	2.1	2.4	2.0	2.1	2.1
After the Experiment (Control Group)	2.3	2.1	2.4	2.1	2.2	2.2
After the Experiment (Experimental Group)	4.4	4.6	4.5	4.7	4.1	4.4

Figure 4: Diagram of the Assessment Results of ICT Competence of Students in the Educational Program for Pedagogical Chemistry (Source: own)

Experimental Results: Physics Program

Students of the educational program for pedagogical physics used ICT to model physical experiments and visualise complex physical processes. This allowed them not only to better understand the fundamental physical laws and principles but also to learn how to explain these phenomena in an accessible language, which is extremely important for future teachers. The use of interactive simulations and virtual laboratories helped to increase students' interest in the subject and develop their analytical skills.

Figure 5 presents the results of assessing various aspects of information and communication competence among students for pedagogical physics before and after the experiment conducted as part of the study. The assessment of ICT competence was also divided into six skills. It shows that in each skill, students in the experimental group significantly increased grades after the experiment compared with their baseline level and with the results of the control group, which adhered to traditional teaching methods.

Operational skills: In the experimental group, the skill level increased from 2.3 to 4.4, indicating a significant improvement in the ability to work with ICT.

Information skills: Here the improvement was from 2.1 to 4.5, demonstrating an increase in skills in finding, evaluating and using information.

Communication skills: the score increased from 2.5 to 4.7, which is one of the most considerable improvements and reflects the development of effective communication skills.

Critical thinking and problem-solving: In this category, the results increased from 2.3 to 4.5, emphasising the development of analytical abilities and the ability to solve complex problems.
Project management: the increase from 2.2 to 4.2 shows that students have improved at organising their work and managing time and resources.
ICT security and ethics: Here, the improvement from 2.1 to 4.4 indicates increased awareness of the importance of security and ethical standards in the field of ICT.

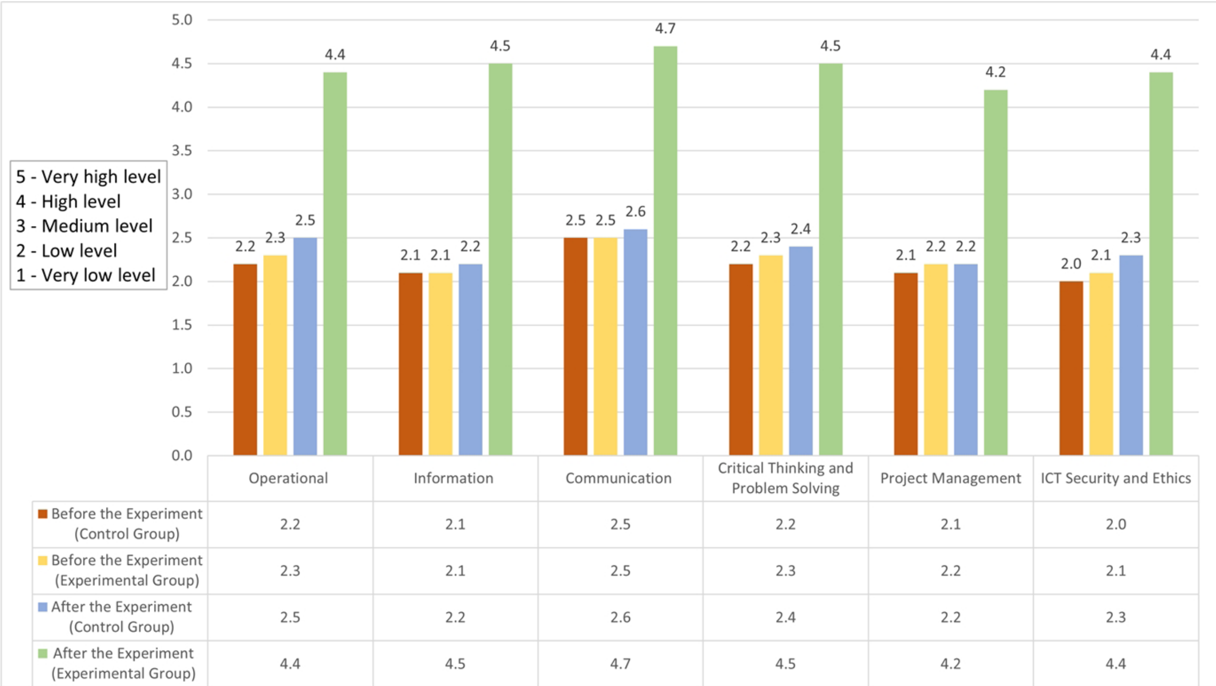


Figure 5: Diagram of the Assessment Results of ICT Competence of Students in the Educational Program for Pedagogical Physics (Source: own)

Results of the Mann-Whitney U-Test of Educational Programs

Our results indicate that the integration of ICT into the laboratory work had a significant positive impact on the development of information and communication competence of students of educational programs of biology, chemistry, and physics. Improvements were seen in all ICT skills: operational skills, information skills, communication skills, critical thinking and problem solving, project management, ICT security and ethics (Table 6).

Educational program	Group	*U*-statistic	*P*-value	*Z*-value	*R*-value	Result
Pedagogical Biology	Control Group	259.5	0.55	-0.59	-0.08	Accepted
	Experimental Group	0.0	2.09e-09	-5.94	-0.86	Rejected
Pedagogical Chemistry	Control Group	256.5	0.51	-0.65	-0.09	Accepted
	Experimental Group	0.0	2.0e-09	-5.94	-0.86	Rejected
Pedagogical Physics	Control Group	234.5	0.254	-1.10	-0.16	Accepted
	Experimental Group	0.0	2.0e-09	-5.94	-0.86	Rejected

Table 6: Results of Mann Whitney U-Test (Source: own)

In all educational programs (pedagogical biology, pedagogical chemistry and pedagogical physics), extremely low p-values are observed for experimental groups (on the order of 2.09E−09 and 2.00E−09), which confirms statistically significant differences between the control and experimental groups. High negative values of *Z-statistic* (-5.94 for all programs) indicate significant deviations, and *R-values* (-0.86 for experimental groups) indicate a strong negative correlation. These data indicate a significant impact of the intervention, which indirectly confirms the presence of a large effect of magnitude. The study results demonstrate statistically significant improvements in the ICT competence of future teachers in the experimental groups compared with the control groups in all educational programs and essential skills considered. This allows us to confidently reject the null hypothesis 7 and confirm the alternative hypothesis 7, according to which the introduction of ICT tools into the educational process positively affects the ***formation of students' ICT competence***. Thus, the study confirms the importance and necessity of integrating ICT into laboratory works to improve the ICT skills of future specialists in the field of pedagogy of natural sciences.

Results of the Interviews

The interview was conducted with the aim of a deeper analysis of the level of students' ICT competencies and verification of the questionnaire data obtained. Through an open discussion with the respondents, the practical aspects of their use of ICT in educational activities were clarified. The questions covered the same key aspects as in the questionnaire, such as operational, information, communication skills, critical thinking and problem solving, project management and digital security and ethics.

The results of the responses showed that the data obtained largely coincided with the results of the questionnaire survey, confirming the average and below average level of ICT competencies among most students. Students demonstrated confidence in using basic ICT tools, but often faced difficulties in solving more complex tasks such as data processing and Internet security.

DISCUSSION

Kormakova et al. (2021) and Wong and Daud (2018) explore the essential skills required by teachers, highlighting the impact of these competencies on teaching efficacy and student engagement. Conversely, for example, the study by Maende and Opiyo (2014) examines the broader structural and systemic elements involved in deploying ICT in education nationally. This analysis details the critical roles of various stakeholders, including government entities and policy frameworks, emphasising a comprehensive and cooperative approach crucial for effectively integrating ICT in educational infrastructures.

The Teachers' Digital Competence Frameworks by Kiryakova and Kozhuharova (2024) and the ICT Competence Framework for Higher Education (UNESCO, 2018), both emphasise the development of essential digital skills for effective technology integration in teaching. Frameworks like DigCompEdu (Redecker, 2017) focus on areas such as digital literacy, pedagogical application, and digital citizenship, while the Kazakhstani framework additionally stresses self-efficacy, attitudes towards ICT, and institutional infrastructure. These frameworks informed the structure of the present study, particularly in selecting key competence areas for evaluation. The study's findings confirm that targeted ICT integration supports the development of operational, informational, and communication skills, aligning with the priorities outlined in the frameworks. Furthermore, the role of institutional support identified in the Kazakhstani context was reflected in the results, reinforcing the need for comprehensive training programs and supportive policies.

The decision not to use other standardised surveys was based on the fact that they did not consider the requirements for measuring the specific six ICT skills we sought to evaluate. In the study by Caluza et al. (2017), the survey on the assessment of ICT competencies of public-school teachers was divided into two domains: Technology Operations and Concepts and Pedagogical Indicators. The division of questions into blocks for all ICT skills ensured focus and accuracy in the assessment, allowing for a thorough examination of every aspect of ICT competence. This facilitated the analysis, making it possible to study in-depth the strengths and weaknesses of learning in each specific area of ICT.

The survey elements used in this study were tested for compliance and reliability using Cronbach's alpha coefficient of 0.89. Furthermore, McDonald's Omega coefficient was computed, yielding similarly high results and further supporting the internal consistency of the questionnaire. The high reliability indices indicate that the questionnaire items are well interconnected. Thus, it allows us to confidently use this questionnaire to research further and assess students' ICT competence.

Only physics pedagogical students (N = 126) participated in the study by Firmansyah et al. (2020). We tested three different pedagogical specialties (N = 115). In both studies, there were samples from only one institution. In a follow-up study, we would like to conduct research at other universities, possibly from different countries, to compare the results.

The study's findings highlighted the importance of integrating various ICT tools into laboratory work to enhance future teachers' digital competencies. Students also recognised the potential benefits of incorporating virtual laboratories into the learning process, highlighting a promising direction for the future development of ICT integration in education. The advantages of a virtual laboratory over a physical one, regardless of whether the latter is used for on-site or remote work. Advantages include savings benefits, flexibility, multiple access points, manageable changes to system configuration, damage resistance, and the ability to make the unseen visible. Expected advances and emerging trends lie in the area of alternative input and output devices for virtual worlds (e.g., haptic/force feedback, motion sensing, stereoscopic displays). The advent of consumer-level immersive VR headsets (e.g., Oculus Rift) may also have implications for the field. Implementing immersive education, distance learning, and virtual worlds open up significant questions in pedagogy and the design of effective learning experiences (Brabec et al., 2024; Potkonjak et al., 2016). As a further study, we can take a course not only on the use of ICT tools during laboratory work but also on the introduction and use of virtual laboratories in the educational process, which can also positively affect the formation of ICT competence of future teachers.

Limitations

Several limitations need to be considered. First, we selected respondents from only one university, so the sample was not representative enough to generalise the conclusions. On the other hand, our research describes the path we want to take in the future and can become an inspiration for other researchers. Follow-up studies should create a sample from multiple institutions in one or more countries with similar educational systems (e.g., CIS or CEE countries) while aiding the data from interviews and test results. This should help to reduce the bias resulting from self-reported data and common-method variance (CMV) that might artificially inflate relationships among study variables (Sharma, Yetton, and Crawford, 2009).

Virtual labs in science education have emerged as a viable and potentially transformative alternative to traditional hands-on laboratory experiences. Even though every strategy has advantages and disadvantages of its own, the best option should be determined by the limits, resources, and particular learning objectives. Virtual labs are instrumental in scenarios where traditional labs are not feasible since they can improve accessibility, scalability, and cost-efficiency (Asare et al., 2023). This confirms the relevance of research and can also contribute to the formation of ICT competence among students of pedagogical specialties.

CONCLUSION

The findings confirm the pivotal role of ICT in enhancing students' communication skills, improving laboratory interactions, and boosting motivation. However, challenges such as unequal access to technology and the need for extensive teacher training persist. Integrating ICT into the education system has emerged as a crucial element in improving the pedagogical landscape, particularly in training future teachers in the field of natural sciences. This research highlights the transformative potential of ICT in the development of information and communication competencies among aspiring teachers, demonstrating a marked improvement in these competencies through the innovative use of ICT in the laboratory.

Empirical data collected during the research demonstrate a positive correlation between the integration of ICT and the improvement of information and communication competencies. Students who have used ICT tools in laboratory work demonstrated excellent operational, information, communication skills, and critical thinking. These findings not only advocate for the inclusion of ICT in the curriculum but also highlight the need for educational institutions to re-evaluate and adapt their teaching strategies to train teachers who can navigate the digital landscape.

In conclusion, the advent of ICT represents a pivotal shift in educational methodologies, particularly within the natural sciences. Our research confirms the positive impact of integrating ICT on the development of future teachers' competencies and serves as a catalyst for further investigation into innovative pedagogical approaches.

Future research should be directed toward several key areas that build upon the findings of this study. First, it is important to assess the long-term impact of ICT integration on the professional training and career development of graduates, examining how the skills acquired during their studies influence their future success. In addition, further research should analyse the ways in which ICT transforms traditional teaching methods, identifying which innovations are most effective across different educational settings. Another important direction involves determining the most suitable ICT tools and pedagogical strategies for various learning environments, including online, blended, and traditional classroom formats. Finally, there is a need to develop, implement, and test new pedagogical approaches and ICT solutions aimed at enhancing the quality of education and improving educational interactions. Addressing these areas will contribute to a deeper understanding of the role of ICT in modern education and support the creation of more effective, adaptive learning environments.

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APPENDIX

SURVEY QUESTIONS

The assessment in the submitted questionnaire is based on a 5-point Likert scale, where: *1 – 'very bad', 2 – 'unsatisfactory', 3 – 'satisfactory'/'neutral', 4 – 'good', 5 – 'very good'.*

Block 1. Operational skills

1. How do you rate your text formatting skills in a text editor?
2. How confident can you insert images and create tables in text documents?
3. Evaluate your level of familiarity with the functions of a text editor for creating professionally designed documents.
4. How often do you use modelling software in educational or research projects?
5. How well do you understand the principles of the modelling program?
6. How do you assess your ability to quickly master new functions in specialised software?

Block 2. Information skills

1. How do you rate your skills in searching scientific sources in databases?
2. How effectively can you assess the reliability of scientific information?
3. How often do you use Excel to analyse data?
4. Evaluate your ability to visualise data using Excel.
5. How well can you organise and analyse large amounts of data?
6. What is your confidence level in using advanced Excel functions for data processing?

Block 3. Communication skills

1. How do you rate your science blogging skills?
2. How well do you know how to discuss and present the results of laboratory work in a blog?
3. How often do you organise online conferences to present projects?
4. Evaluate your ability to effectively interact with the audience during online presentations.
5. How well do you know how to use digital collaboration tools?
6. How do you assess your ability to adapt communication styles for different platforms?

Block 4. Critical thinking and problem-solving

1. How often do you apply theoretical knowledge in virtual laboratories?
2. How successfully do you solve practical problems using virtual experiments?
3. How do you rate your skills in analysing real cases?
4. How effectively do you develop solutions to complex problems?
5. How often do you use analytical thinking to solve problems?
6. Evaluate your ability to think innovatively in difficult situations.

Block 5. Project management

1. How do you rate your ICT project planning skills?
2. How successfully do you allocate tasks and resources in projects?
3. How often do you participate in project management?
4. Evaluate your ability to coordinate the activities of the team within the framework of projects.
5. How well do you handle time management in projects?
6. How do you assess your ability to adapt to changes and surprises during the course of the project?

Block 6. Security and ethics in the field of ICT

1. How do you assess your knowledge of the principles of digital security?
2. How well do you understand the laws and regulations governing data protection?
3. How often do you update your data security software?
4. How well are you aware of the methods of preventing cyber-attacks?
5. How do you assess your ability to conduct security training for other users?
6. How often do you face ethical dilemmas in ICT and how do you solve them?

INTERVIEW QUESTIONS

1. Operational skills:

- Can you tell us how you usually work with text editors (for example, Microsoft Word or Google Docs)? What functions do you use most often?
- Describe how you create tables and work with data in spreadsheets (for example, Excel, Google Sheets). What types of data are you processing?
- What types of presentation software have you worked with? How do you structure information in your presentations?

2. Information skills:

- How do you search and evaluate the reliability of information on the Internet or in scientific databases?
- Can you tell us about your experience in data processing (for example, in laboratory work)? What tools have you used for data analysis?

3. Communication skills:

- How do you use digital platforms for communication and collaboration (for example, social networks, messengers, online conference tools)?
- Can you describe how you presented your work or projects on digital platforms? What problems have you encountered while doing this?

4. Critical thinking and problem-solving skills:

- Describe a case where you needed to solve a practical problem using ICT. What tools did you use and how did you come to a decision?
- How do you approach information analysis and decision-making based on data obtained from digital sources?

5. Project management skills:

- How do you organize your work in the framework of projects using ICT? What tools do you use to plan and distribute tasks?
- How do you coordinate the work of the team or your tasks within the framework of training projects?

6. Security and ethics in ICT:

- How do you protect your personal data and project data on the Internet? What security measures do you take?
- What ethical aspects of using ICT are important to you, and have you faced ethical dilemmas when working with information technology?

Full research paper

THE ROLE OF PERSONAL AND SOCIAL RESPONSIBILITY ON FUTURE PHYSICAL EDUCATION TEACHERS' BULLYING ATTITUDES

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ABSTRACT

Although physical education provides significant opportunities to promote physical activity, the nature of movement-performance-based, multidimensional classroom dynamics can make students primary targets for bullying, particularly in areas such as gymnasiums or even changing rooms. Therefore, teachers' interventions and awareness are critical. To create effective anti-bullying programs for teacher candidates, this study examined the impact of personal responsibility (PR) and social responsibility (SR) on attitudes towards bullying. It also highlights the possible effects of gender, year of study, and teaching experience. A total of 164 Hungarian physical education teacher candidates (PETCS) studying in the 3rd to 5th years completed questionnaires. The majority of PETCs had a high level of positive bullying attitudes, PR, and SR. While there were significant differences in bullying attitudes at gender and year of study, no differences were found in teaching experience. A significantly strong relationship was found between SR and various attitude sub-dimensions. Analyses showed a predictive effect of SR, gender, and year of study on several bullying attitudes, while PR did not show any significant effect. Since attitudes are an important factor in creating a safe classroom environment, the focus of preventive and educational programs against bullying should include developing SR.

KEYWORDS

Bullying attitudes, bullying prevention, personal responsibility, preservice teachers, social responsibility

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Highlights

- *A significant relationship exists between physical education teacher candidates' social responsibility and their attitudes towards bullying.*
- *It was determined that physical education teacher candidates' individual values, such as social responsibility, were significant factors in shaping their attitudes towards bullying.*
- *Results indicated that bullying attitudes varied by gender and year of study, but teaching experience had no effect.*

INTRODUCTION

Bullying is defined as the deliberate and repeated use of words or actions against an individual or group of people with the intention of making others feel powerless and helpless, thereby causing distress and endangering their well-being (AHRC, 2011). Bullying is regarded as a major problem in many nations and, may "*even pose a threat to public health* (Gladden et al., 2014: 4)" given its wide ranging short and long term consequences including well-being, mental, physical, emotional, social, behavioural, and academic outcomes (Copeland et al., 2013; Hendricks and Tanga, 2019; Kallman, Han and Vanderbilt, 2021). It is known that incidents such as bullying, disruptive behaviours, and physical or psychological violence are becoming more common in schools. According to OECD (2023: 95), approximately 20% of students reported being bullied, threatened, or witnessing fights on school grounds at least once a month. General overview of bullying ranging from 8.3% to 34.2% depending on the country (Twardowska-Staszek, Zych and Ortega-Ruiz, 2018; Fischer et al., 2020; Kilicaslan et al., 2023).

While bullying in school settings has been studied relatively extensively and is considered a serious problem, little is known about bullying in physical education (PE) classes, and more information is needed to address bullying in this context (O'Connor and Graber, 2014; Borowiec et al., 2022). Although PE classes are an ideal environment to promote physical activity and healthy lifestyles, due to the dynamics of the classroom (*less adult supervision, more pronounced physical differences, large group settings, and competitive nature*) it can be an suitable environment where students are the primary targets of bullying, especially in areas such as changing rooms, gymnasiums, or athletic fields (O'Connor and Graber, 2014; Jiménez-Barbero et al., 2020; Ball et al., 2022). Studies show that many students are mocked, ignored, discriminated against, bullied in PE classes and sports activities due to physical appearance, body image, gender, poor motor skills, or physical ability and disabilities (O'Connor and Graber, 2014; Benítez-Sillero et al., 2021; Ball et al., 2022; Bejerot, Ståtenhag and Glans, 2022; Borowiec et al., 2022; Sağin, Uğraş and Güllü, 2022). As a result, in addition to the negative effects mentioned above, victims participate less in PE and physical activity, have less enjoyment, and lose interest (Roman and Taylor, 2013; O'Connor and Graber, 2014; Jachyra, 2016; Jiménez-Barbero et al., 2020; Sağin, Uğraş and Güllü, 2022). Since children spend most of their time at school, "*teachers are often the first adults whom students can contact when they face bullying in schools* (Wachs et al., 2019: 644). Research has shown that although students expect teachers to actively intervene (Wachs et al., 2019; Demol et al., 2021), they also report that teachers' actions can worsen the incident (Sağin, Uğraş and Güllü, 2022). The majority of research suggests that teachers often fail to identify bullying incidents, overlook them, or are unable to intervene promptly (Eijigu, 2021; Rigby, 2014; Yoon et al., 2016). Although many international studies have shed light on bullying in PE classes, no such study has been found in Hungary.

While research has focused largely on teachers of other disciplines, little is known about physical education teachers (Wei and Graber, 2024), especially physical education teacher candidates (PETC). Studies with physical education teachers highlight that teachers' and coaches' intervention tendencies vary according to the student's gender (Peterson, Puhl and Luedicke, 2012). Moreover, teachers often address physical bullying and tend to be less attentive to verbal and relational bullying (O'Connor and Graber, 2014). The literature further confirms that teachers acknowledge the existence of bullying; however, they are often ineffective in systematically preventing certain students from being targeted by peer bullying (Sağin, Uğraş and Güllü, 2022; Wei and Graber, 2024). It is important to know the responses and strategies that PETC will use to receive specialised anti-bullying training. Therefore, drawing attention to the pre-service period will be an important step. Ríos, Ventura, and Prat (2023) indicate that PETC lacks confidence in dealing with bullying and often adopts superficial strategies. They perceive that poor classroom management can pave the way for bullying. Castillo-Retamal et al. (2023) found that candidates were aware of the negative effects of bullying. The authors also noted that although they had not received any training on bullying, 60% stated that they could identify physical and verbal forms of violence. Consistent with this, earlier research indicates that teacher candidates are better at recognizing or intervening in physical bullying (Boulton et al., 2014; Dawes, Starrett and Irvin, 2024) but less effective in addressing relational bullying (Yoon, Sulkowski, and Bauman, 2016; Huang, Liu, and Chen, 2018). Overall, studies highlight significant gaps in candidates' knowledge (Begotti, Tirassa and Acquadro Maran, 2017) and the skills required for prevention (Mahon, Packman and Liles, 2023). They also indicate that candidates frequently tend to overlook incidents (Fry et al., 2020), even though they have mainly negative attitudes toward bullying (Lester et al., 2018).

"Teachers have a responsibility to proactively quell unnecessary bullying that has some students terrified to attend PE, a class that may provide them with their only structured physical activity outlet during the school day (O'Connor and Graber, 2014: 406)." To mitigate the negative effects of bullying and achieve favorable outcomes, families, schools, and educators must recognize their collective societal responsibilities. For this purpose, the teaching of personal and social responsibility has been used to develop many positive values, such as effort, respect, and conflict management, alongside sports behaviors in PE (Sánchez-Alcaráz, Gómez-Mármol and Valero-Valenzuela, 2019). While our study does not implement the model itself, we adopt the core concept as a framework to enable individuals to take ownership of their actions as personal responsibility (PR) and to become more sensitive to the needs of others through social responsibility (SR) (Lavay, 2019). A large body of research examining the effects of personal and social responsibility on students' bullying behaviours (Sánchez-Alcaráz, Gómez-Mármol and Valero-Valenzuela, 2019; Ioannis, 2024). While a few studies have examined the effects on university students (Soos et al., 2025), there seems to be insufficient emphasis on the responsibility of in-service and preservice teachers in the PE context. Physical education teachers or PETC' are expected to exhibit PR in the educational environment under the "inner sense of obligation, duty or commitment (Lauermann and Karabenick, 2013: 13)" and in addition to this, SR, framed by ethical and moral values, implies without prioritising their self-interest, protecting and improving the well-being of the society and the environment by fostering a positive impact. While PR provides an inner strength for individuals to take responsibility for the decisions or actions they make and overcome the problems they encounter along the way, SR supports the creation of an inclusive classroom environment where students feel safe, promote respect and empathy. Personal and social responsibility appear to have an impact on respect towards others, self-control (Escartí et al., 2010), violent attitudes (Sánchez-Alcaráz, Gómez-Mármol and Valero-Valenzuela, 2019), bystander and prosocial behavior (Nickerson et al., 2024; Pérez Ordás, Pozo and Cruces, 2020) in the PE context. Studies in the literature show that teachers/candidates tend to take responsibility for intervening in bullying (Ellis et al., 2016; Gizzarelli, Burns and Francis, 2023). Yet, they have difficulties in detecting bullying in the classroom, as they believe it mostly occurs in the corridors and outside the school; therefore, they tend to pass on the responsibility to administrators and other teachers in these areas (Mahon, Packman and Liles, 2023).

Aims and Research Questions

Recent research on bullying appears to fall short in explaining why some teachers/teacher candidates exhibit intervention behaviours such as tackling bullying or helping the victim, while others tend to ignore it. It is well recognized that a wide range of characteristics influences teacher candidates' attitudes towards bullying, and that these factors may affect how they respond to bullying incidents in teaching practice or in an actual school setting in the future. Previous studies have identified demographic factors, such as gender, age, or teaching experience, as being associated with perceptions of bullying or taking responsibility in responses to those incidents (de las Heras et al., 2022; Soos et al., 2025). Studies indicate that female teacher candidates generally show higher empathy and intervene more frequently, whereas senior candidates tend to take the incident more seriously. With greater teaching experience, they often report higher self-confidence and a greater likelihood of intervening (Amanaki and Galanaki, 2014; Lester et al., 2018). The attitudes or behaviours of PETC towards bullying are complex and not one-dimensional. Especially, PETC tend to adopt the same teaching style and teaching approaches they experienced during their student years (Wei and Graber, 2024), making teacher training indispensable for changing these beliefs. Up to this date, studies on bullying attitudes have largely focused on teachers or students, with only a few studies examining the responses of teacher candidates (Mahon, Packman and Liles, 2023), and this gap is even more evident in the context of PE (Wei and Graber, 2023). While responsibility studies mainly focus on teachers' accountabilities or students' educational outcomes (Çetin and Eren, 2022), research on teacher candidates remains limited (Lauermann and Karabenick, 2013; Eren, 2014; Eren and Çetin, 2019). So far, attitudes are known to be an important factor in understanding behaviours, but it has remained largely unclear how PETC's sense of responsibility might relate to forming these beliefs. We believe that this study represents a fundamental element for the development of both theory and intervention research, and it holds an important place in understanding the factors that may positively or negatively influence candidates' standpoints. Although these studies provide important insight into the potential reactions of teacher candidates to bullying, studies addressing PE, particularly in Hungarian PETCs, remain under-documented and inadequately analysed. In light of the insufficiency of research, this study seeks to explore the following questions: a) Are there any differences in the levels of personal and social responsibility and attitudes toward bullying among PETCs based on demographics? b) What is the relationship between personal and social responsibility levels and attitudes towards bullying among PETC? c) To what extent do demographics, personal and social responsibility levels predict PETC's bullying attitudes?

MATERIALS AND METHODS

Design

The study was conducted using a quantitative methodology, employing a correlational survey method to inductively examine the relationships between teacher candidates' sense of responsibility, their attitudes towards school bullying, and the research variables.

Participants

The study population consists of 3rd-, 4th-, and 5th-year PETCs studying in Budapest. A total of 164 students participated in the study. Among these participants, 84 (51.2%) were female, 80 (48.8%) were male (M_{gender} = 1.48). As for year of study, 67 (40.9%) were 5th year, 39 (23.8%) were 4th year, and 58 (35.4%) were 3rd year students (M_{class} 2.05). Regarding teaching/coaching experience, 124 (75.6%) had experience, while 40 (24.4%) did not have teaching/coaching experience ($M_{experience}$ = 1.24).

Instruments and Data Collection Procedure

The ethical permission was obtained from the Hungarian University of Sports Science Ethics Board (MTSE-KEB/No09/2025). After the purpose of the research was explained to the participants, data were collected voluntarily, outside class hours, in accordance with ethical rules. The data was collected via Google Forms in April 2025.

Demographic Form: the form consists of the information about the participant's gender, teaching/coaching experience, and year of study.

Personal And Social Responsibility Questionnaire (PSRQ): Participants completed a Hungarian translation of PSRQ developed by Watson, Newton, and Kim (2003) for measuring responsibility in PE. The questionnaire was later adapted for the school context by Li, Wright, and Rukavina (2008) and for the Hungarian and Spanish university contexts by Soos et al. (2025). For this study, the questionnaire was further modified to apply to PETC. For instance, the item *"I give a good effort"* was adapted for the educational environment as *"I work hard to perform well in the classroom*." This 6-point Likert-type scale has two sub-dimensions, each with seven items, called Social Responsibility (α = .88) and Personal Responsibility (α = .81). Total Responsibility Cronbach's α coefficient was .88. Reverse-coded item 14 was removed due to its low factor loading and Cronbach value.

Attitudes Toward School Bullying Scale: Attitudes towards bullying were assessed with the Hungarian translation of the *Attitudes Toward School Bullying Scale* developed by Yeşilyaprak and Dursun Balanuye (2012). The questionnaire was further modified in this study so that the PETC can understand possible situations. The scale is a 5-point Likert-type scale consisting of 25 items. Extended version *"students who witness bullying and remain silent will allow the bullying to continue*." to give deeper understanding we add context for "staying silent" such as *(e.g., by not reacting, not reporting it to an adult)* or *"I hate the bully,"* to *"I feel a deep hatred toward the bully due to their harmful and destructive behaviours*" to direct the negative emotion toward the situation rather than directly toward a person. The scale consisted of four subscales, including Ignoring (10 items, α = .71), Humanistic (7 items, α = .73), Authoritarian (4 items, α = .57), and Tough (4 items, α = .76) Attitude. The Cronbach value for the overall scale was .79.

In the original study the Cronbach value for the overall scale was .78 and the subscales varied between .55 to .72. While higher scores in total attitudes reflect are more conscious, sensitive, prone to bullying in recognising and noticing bullying, high scores in subscales indicate; Ignore: dismissive approach; Humanistic: empathic and supportive approach; Authoritarian: delegate handling to the administrators; Tough: harsh and punitive approach.

Data Analysis

Statistical analysis was performed with SPSS 29.00 and Jamovi software. To verify normality, we used Kolmogorov-Smirnov. The results of the test showed an absence of normality. After descriptive statistics (mean, median, SD, skewness, and kurtosis), internal consistency was assessed using Cronbach's alpha, reflecting acceptable to good levels of reliability except for the Authoritarian subscale with four items (.57), which is below the ideal levels, but this is anticipated and accepted due to the limited items (Taber, 2018). Mean comparisons and significance testing were conducted using nonparametric tests. The Mann-Whitney U test was used for comparing two samples, and the Kruskal-Wallis test for more than two samples, followed by the Bonferroni post hoc test. Associations were examined using Spearman correlation, direct effects were evaluated with GLM multivariate analysis, and prediction was evaluated with Hierarchical Regression Analysis. Effect size was calculated by using partial eta squared (η^2), with values interpreted as a small $\eta^2 = 0.01$, medium $\eta^2 = 0.06$, and large $\eta^2 = 0.14$ (Richardson, 2011). A significance level of $p < 0.05$ was used for the interpretation of all statistical results.

RESULTS

The Mann-Whitney U test was employed to analyse whether there were differences according to gender. As shown in Table 1, female candidates scored significantly higher scores in Ignore, Humanistic, Tough, and Total Attitude subscales compared to male candidates ($p \leq .05$). In addition, there is no difference in the PR, SR, Total Responsibility, Tough, and Authoritarian Attitude sub-scales ($p > .05$).

			n	Mean Rank	*U*	*p*	*r*
Personal and social responsibility subscales	*PR*	Female	84	84.56	3787.000	.568	-
		Male	80	80.34			
	SR	Female	84	85.46	3111.500	.405	-
		Male	80	79.39			
	TR	Female	84	85.48	3119.500	.410	-
		Male	80	79.37			
Attitudes towards school bullying subscales	Ignore	Female	84	94.54	2349.000	.001*	-0.26
		Male	80	69.86			
	Humanistic	Female	84	91.70	2587.000	.011*	-0.19
		Male	80	72.84			
	Authoritarian	Female	84	80.86	3222.000	.647	-
		Male	80	84.23			
	Tough	Female	84	92.59	2512.500	.005*	-0.21
		Male	80	71.91			
	Total Attitudes	Female	84	95.02	2308.500	< .001*	-0.27
		Male	80	69.36			

**p < 0.05; TR = Total Responsibility*

Table 1: Results of the Mann-Whitney U test for comparing bullying attitudes and responsibility level based on gender

The Kruskal-Wallis test results, as shown in Table 2, indicated significant differences across years of study in the Ignore, Humanistic, and Authoritarian Attitude sub-scales ($p < .001$). Post-hoc comparisons revealed that the 4th year students exhibited significantly higher scores in Ignore and Humanistic Attitude. Notably, 5^{th}-year candidates exhibit the highest Authoritarian and the lowest humanistic attitudes. On the other hand, no significant differences were found in PR, SR, Total Responsibility, Tough, and Total Attitudes across groups ($p > .005$).

To explain clearly the interaction between attitudes towards school bullying and responsibility, a scatter plot was created (Fig. 1). The Mann-Whitney U test was applied to examine whether there were significant differences based on teaching/coaching experience. According to Table 3, no statistical difference was observed between those with teaching/coaching experience and those without teaching/coaching experience on bullying attitudes and responsibility levels ($p > .05$).

Variable	Year of study	x^2	*df*	*p*	Mean Rank	Group comparison	Adjusted *p*-value
PR	3rd year	5.19	2	.07	71.12		
	4th year				88.87		
	5th year				88.64		
SR	3rd year	2.97	2	.22	81.77		
	4th year				93.09		
	5th year				76.97		
Total Responsibility	3rd year	3.30	2	.19	74.65		
	4th year				92.37		
	5th year				83.55		
Ignore	3rd year	23.17	2	< .001*	90.78	5th-3rd year	.002*
	4th year				105.23	5th-4th year	.000*
	5th year				62.10	-	-
Humanistic	3rd year	25.36	2	< .001*	93.39	5th-3rd year	.000*
	4th year				103.87	5th-4th year	.000*
	5th year				60.63	-	-
Authoritarian	3rd year	17.88	2	< .001*	69.17	5th-3rd year	.000*
	4th year				70.17	4th-5th year	.003*
	5th year				101.22		
Tough	3rd year	4.34	2	.11	79.53		
	4th year				96.14		
	5th year				77.13		
Total Attitudes	3rd year	5.62	2	.060	80.40		
	4th year				97.76		
	5th year				75.44		

*Note: *Bonferroni adjusted Dunn test significance*

Table 2: Results of the Kruskal-Wallis Test for comparing bullying attitudes and responsibility level based on year of study

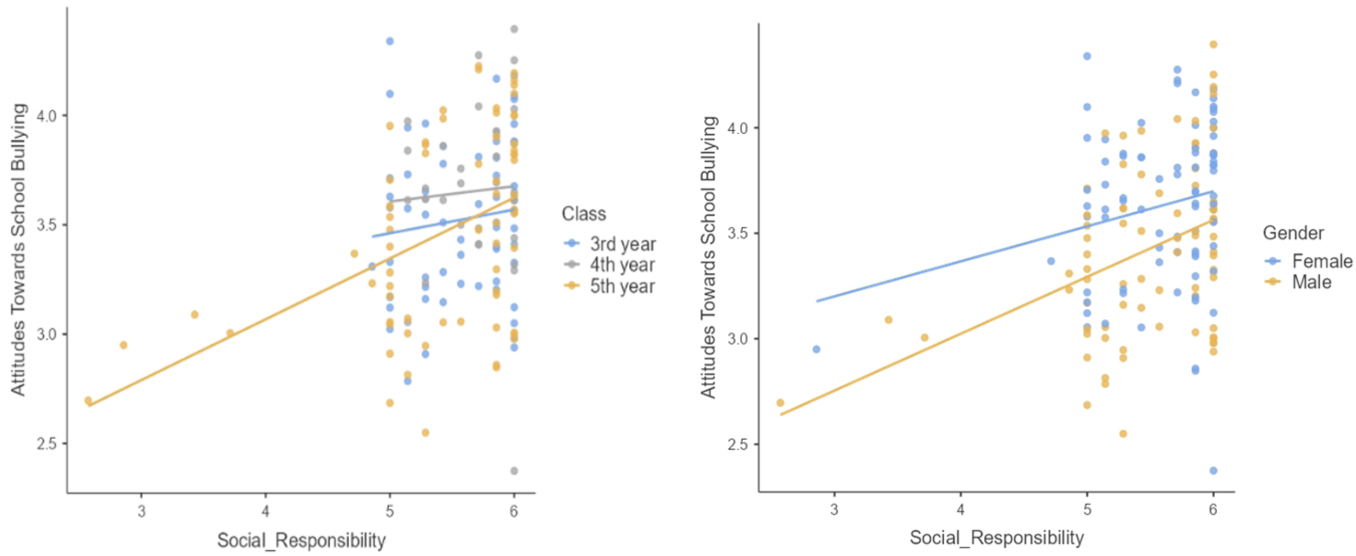

Figure 1: Scatter Plot

			n	Mean Rank	*U*	*p*
Personal and social responsibility subscales	PR	Yes	124	85.21	2144.500	.197
		No	40	74.11		
	SR	Yes	124	85.30	2132.500	.175
		No	40	73.81		
	Total Responsibility	Yes	124	85.21	2144.000	.198
		No	40	74.10		
Attitudes towards school bullying subscales	Ignore	Yes	124	84.54	2226.500	.331
		No	40	76.16		
	Humanistic	Yes	124	83.82	2316.500	.530
		No	40	78.41		
	Authoritarian	Yes	124	86.48	1986.500	.057
		No	40	70.16		
	Tough	Yes	124	84.71	2206.000	.292
		No	40	75.65		
	Total Attitudes	Yes	124	85.78	2006.000	.070
		No	40	72.33		

Table 3: Results of the Mann-Whitney U test for comparing bullying attitudes and responsibility level based on teaching experience

A correlational analysis was conducted to explore the relationship between responsibility and attitudes. Table 4 summarises the results of Spearman's rank correlation analysis. A very strong positive relationship was found between PR and SR ($r = 0.621$, $p < .001$). SR showed significant but weak correlations with Ignore ($\rho = .220$, $p < .01$), Humanistic ($\rho = .247$, $p < .01$), Tough ($\rho = .193$, p <05) attitudes and a moderate correlation with Total Attitudes ($\rho = .279$, $p < .01$). PR showed only a weak but significant correlation with Total Attitudes ($\rho = .156$, $p < .05$).

	1	2	3	4	5	6	7
1. *SR*	1.00						
2. *PR*	0.621**	1.00					
3. Ignore	.220**	.079	1.00				
4. Humansitic	.247**	.118	.433**	1.00			
5. Authoritarian	.069	.010	.005	-.285**	1.00		
6. Tough	0.193*	0.142	.404**	.213**	.296**	1.00	
7. Total Attitudes	0.279 **	0.156*	.663**	.456**	0.477**	0.829**	1.00

***p < 0.01. *p < 0.05*

Table 4: Correlation analysis of personal and social responsibility and their relationship with bullying attitudes towards bullying

To determine the predictive effects of demographics, PR, and SR levels of PETCs on bullying attitudes, a two-step hierarchical regression was conducted (Table 5). Total Responsibility was excluded due to the multicollinearity problem. The independent variables were entered as follows: Step 1 included gender and year of study, and Step 2 included PR and SR. In the first step, demographic variables significantly explained 13.3% of the variance in Ignore Attitude ($p < .001$). In Step 2, PR and SR were incorporated into the equation, resulting in an improvement in the model, with the variance explained increasing to 18.7% ($p < .001$). SR was the strongest predictor of Ignore Attitude ($\beta = .254$, $p < .01$). In Humanistic Attitude, demographic variables explained 15.5% of the total variance ($p < .001$). In the second step, when PR and SR were added, the model improved. Likewise, SR was the strongest predictor ($\beta = .239$, $p < .05$) along with gender ($\beta = -.239$, $p < .001$) and year of study ($\beta =-.273$, $p < .001$). While the first model explained 10.1% of the variance in the Authoritarian Attitude ($p < .001$), increasing to 11.9% in model 2 ($p < .001$). The best predictor of the model was the year of study ($\beta = .316$, $p < .001$). Tough Attitude showed the lowest variance. While 4.9% was explained in Model 1 ($p = .017$), with the addition of PR and SR, the explanation increased to 9.9% ($p = .002$). The only significant predictor for this attitude was gender ($p < .05$). Finally, for Total Attitude, demographic variables explained 7.3% of the total variance ($p = .002$), while SR and PR added in model 2 increased the explanatory power to 40.3% ($p < .001$). The strongest predictors in the model were determined as gender ($\beta = -.228$, $p < .01$) and SR ($\beta = .315$, $p < .01$). Overall, SR and gender were the most significant factors in predicting PETC's bullying attitudes.

Dependent variable	Model	R	R^2 change	$F(df)$	P	Prediction
Ignore	Step 1	.365	.133	F(2, 161) =12.37	< .001	Gender: β =-.263 t = -3.575** YOS: β = -.266 t = -3.626**
	Step 2	.432	.053	F(4, 159) =9.13	< .001	Gender: β = -.237 t = -3.289** YOS: β = -.228 t = -3.081** SR: β = .254 t = 2.866*
Humanistic	Step 1	.394	.155	F(2, 161) =14.810	< .001	Gender: β = -.265 t = -3.654** YOS: β = -.305 t = -4.202**
	Step 2	.459	.056	F(4, 159) =10.627	< .001	Gender: β = -.239 t = -3.369** YOS: β = -.273 t = -3.738** SR: β = .239 t = 2.736*
Authoritarian	Step 1	.317	.101	F(2, 161) =9.012	< .001	YOS: β = .316 t = 4.422**
	Step 2	.345	.018	F(4, 159) =5.361	< .001	YOS: β = .351 t = 4.544**
Tough	Step 1	.222	.049	F(2, 161) =4.172	.017	YOS: β = .005 t = -2.834*
	Step 2	.314	.049	F(4, 159) =4.340	.002	Gender: β = .011 5 t = -2.575*
Total attitudes	Step 1	.270	.073	F(2, 161) = 6.33	.002	Gender: β = -.261 5 t = -3.439**
	Step 2	.403	.089	F(4, 159) =7.695	< .001	Gender: β = -.228 5 t = -3.121** SR: β = .315 t = 3.495**

*Note: ** p<0.01. *p<0.05; YOS= year of study*

Table 5: Regression analysis of demographic and responsibility predictive roles on bullying attitudes

DISCUSSION

This article aims to investigate how the personal and social responsibility of PETCs affects their attitudes towards bullying and to understand the influence of factors such as gender, year of study, and experience on the formation of these attitudes. Most importantly, it seeks to provide insights into better understanding the factors that influence attitudes and contribute to the development of effective intervention strategies to prevent bullying incidents in PE classes. Many studies show that teacher candidates have negative or positive attitudes towards bullying (Beran, 2005; Craig, Bell and Leschied, 2011; Kahn, Jones and Wieland, 2012; Lester et al., 2018; Kovač and Cameron, 2024). Teacher candidates' attitudes and beliefs about bullying predict whether they will intervene (Banas, 2015; Wei and Graber, 2023). Physical education teachers' attitudes, such as being supportive or authoritarian, influence whether students become victims or bullies (Montero-Carretero and Cervelló, 2019). Therefore, examining the attitudes of PETC is equally important in shaping these early tendencies.

Differences by Demographics in Bullying Attitudes

The literature suggests that individual characteristics, such as gender, age, and experience, are significant factors influencing teachers' perceptions and attitudes towards school bullying (Craig, Pepler and Atlas, 2000; de las Heras et al., 2022). Results from this study revealed that ***gender*** had a statistically significant effect on attitudes. It was found that female PETC seemed to exhibit more Humanistic, Ignore, Tough Attitudes compared to their male peers. Nevertheless, their general attitudes were more constructive and positive. Consistent with these findings, Şen and Doğan (2021) reported that female teachers exhibit more Humanistic and Authoritarian Attitudes than their male peers. Similarly, Peterson, Puhl, and Luedicke (2012) found that regardless of the gender of the bully, female physical education teachers or coaches tended to intervene more than their male counterparts. According to de las Heras et al. (2022), the study reported that 20% of teacher candidates preferred to remain ignorant in the face of bullying. These findings may be explained by women exhibiting greater emotional awareness, making them more sensitive to both the bully and the victim. This interpretation is consistent with previous research indicating that female candidates have higher empathy, concern, anxiety most likely intervene and have higher self-confidence than male candidates (Beran, 2005; Yot-Domínguez, Guzmán Franco and Duarte Hueros, 2019; Gizzarelli, Burns and Francis, 2023; Dawes, Starrett and Irvin, 2024) at the same time, they will be more likely exhibit positive bystander responses than males (Macaulay, Boulton and Betts, 2019). Although some studies have indicated gender differences exist in attitudes toward different types of bullying (Craig, Bell and Leschied, 2011; Dawes, Starrett and Irvin, 2024), others have found no significant gender differences (Boulton et al., 2014; Lester et al., 2018).

According to ***the year of study***, no differences were found in Tough and Total Attitudes, whereas differences emerged in Ignore, Humanistic, and Authoritarian Attitude. In contrast, previous research reported that year of study does not influence attitudes (Dawes, Starrett and Irvin, 2024). It has been determined that PETC's 3rd and 4th year students take bullying less seriously and see it as an expected situation, while 5th year candidates see bullying as a more serious problem. Whereas candidates in earlier years tend to adopt more humanistic approaches, final-year candidates display a more disciplinary approach, attributing responsibility to school administrators. A higher year of study may result in candidates perceiving the problem as more serious, which in turn may lead them to consider a more layered approach and authority as essential in the solution process. Similar to the present study, Lester et al. (2018) revealed that teacher candidates' perceptions of their knowledge, prevention, and management skills regarding bullying differed by year of study. Amanaki and Galanaki's (2014) study revealed that teacher candidates in the final year of study expressed greater concern but less confidence in their ability to effectively address bullying compared to those in lower years. Nevertheless, Huang, Liu, and Chen (2018) found that first-year teacher candidates were more empathic to the victim, perceived bullying more seriously, and reported a greater willingness to intervene. As literature is contradictory on this issue, further investigation is needed.

In this study, no statistically significant difference was found in ***teaching/coaching experience*** on attitudes. Similarly, Dawes, Starrett, and Irvin (2024) found that practical experience did not affect perceived seriousness, empathy, confidence, or intervention likelihood. In contrast, Craig, Bell, and Leschied (2011) found that increased exposure to bullying incidents among teacher candidates was associated with greater confidence and sensitivity in recognising and dealing with bullying.

The results of the Burger et al. (2015) study, which involved teachers, highlighted the importance of experience. They found that teachers with less than five years of teaching experience preferred "enlisting other adults", whereas more experienced teachers preferred to "work with the bully or the victim". This result suggests that young or inexperienced teachers tend to seek assistance from others rather than direct intervention, whereas experienced teachers prefer direct intervention. Goryl, Neilsen-Hewett, and Sweller (2013) found that levels of confidence in addressing bullying were not related to years of teaching or experience; teachers with more or fewer years of teaching felt equally confident. Other studies also support that teachers with higher levels of teaching experience exhibit greater confidence and a higher likelihood of intervening in incidents (Shahrour et al., 2023). These studies indicate that candidates' self-efficacy and intervention methods will change as they gain experience and are exposed to different types of bullying. Therefore, it is essential to acknowledge that experience is a crucial aspect.

Differences by Demographics in Personal and Social Responsibility

It was determined that the sense of responsibility does not differ according to gender, work experience, or years of study. A study by Pozzoli and Gini (2013b) suggests that the sense of responsibility is particularly effective through helping behaviour. In this case, the person must first be aware of the situation, see the incident as an emergency, feel responsible for intervening, know what they are doing, and choose to help. In Mahon, Packman, and Liles' (2023) study, it was revealed that teacher candidates would take responsibility for keeping their students safe, even in the absence of knowledge about bullying or appropriate responses to it. Another finding from the research was that PETC demonstrated a high level of personal and social responsibility. The findings align with Soos et al. (2025), who examined Hungarian and Spanish PETCs and found that Hungarian female PETCs showed a higher personal and social responsibility. A considerable body of research has shown that teachers/candidates take responsibility for attempting to change student behaviour and intervene (Beran, 2005; Craig, Bell and Leschied, 2011; Gizzarelli, Burns and Francis, 2023).

Predictive Effects of Responsibility and Demographics on Bullying Attitudes

Another aim of the current study was to test whether PR or SR would be associated with PETC attitudes. Our findings revealed that SR was significantly positively associated with various attitudes. PETC with higher SR tend to exhibit stronger Humanistic, Tough, Ignore Attitudes. Such candidates are more likely to adopt empathic and supportive approaches while also endorsing disciplinary strategies in certain contexts, and may exhibit avoidance. An important study by Dawes and Lohrbach (2025) revealed that teacher candidates employ multiple strategies to deal with bullying, ranging from student-centered approaches, such as "referring to a counsellor," to strategies that shift responsibility to others, such as "involving the school principal." Therefore, whether candidates take responsibility for their interventions and responses to bullying or avoid it makes a significant difference. On the other hand, PR was not significantly associated with variables except for a weak positive correlation with overall attitudes. Although PR played a relatively small role, it should be borne in mind that "according to the Bystander Intervention Decision Model, even if a person accepts that the incident is serious or wrong during the intervention, their intervention likelihood will depend on their perception of personal responsibility" (Latané and Darley, 1970; Thornberg, Landgren and Wiman, 2018).

A further aim was to investigate the effects of demographics and responsibility on bullying attitudes in more depth. Hierarchical regression analysis was performed to determine the predictive role to support these findings. The results of the hierarchical regression analysis were as expected; SR was a strong and significant predictor of Ignore, Humanistic, Tough, and overall positive attitude. The effect of SR in the model remained significant even when other variables were controlled, revealing its importance as an independent predictor. On the other hand, PR did not make a significant contribution to attitudes. Among the demographic variables, gender was found to have a high predictive effect, especially in the Ignore, Humanistic, Tough, and total attitude dimensions.

In contrast, the year of study was found to predict the Ignore, Authoritarian, and Tough dimensions. According to a study by Ellis and Shute (2007), teacher reactions to bullying are shaped by their moral orientations and influence the type of response they provide. Those with a care moral orientation predicted a problem-solving response (*empathy, compromise, etc.*), while those with a justice orientation predicted a rules and sanctions (*punishment, discipline*) response. In this regard, SR can be understood as the ethical obligation that an individual feels toward their surroundings, such as ensuring justice and adhering to rules, and is driven by internal motivation rather than external pressure. However, the largest impact relates to the perceived seriousness of the bullying incident.

For this reason, it is important to foster values such as PR and SR awareness in teacher education. In line with our results, other studies revealed that responsibility predicts an individual's willingness to intervene in bullying incidents (Chen, Chang and Cheng, 2016; Yoon, Sulkowski and Bauman, 2016; Dawes and Lohrbach, 2025) and that SR strongly predicts prosocial behaviours and social skills (Wray-Lake, Syvertsen and Flanagan, 2016; Wei et al., 2023). Although PETCs report a high level of SR, how they perceive SR (e.g., ensuring justice or adhering to rules) in this context remains unclear, which may explain the diverse responses of PETCs. Further research should be conducted on how SR or PR is internalized. Another possible explanation is that people may tend to exhibit more than one reaction in complex situations. Wei and Graber (2024) found particularly striking results for PETCs. Physical education teachers' attitudes towards bullying and their decisions to intervene were influenced by their past experiences and teacher training. People who have had experiences of being both a bully and a victim in their past are likely to develop more than one approach. Likewise, teacher candidates tend to rely on both discipline/punishment and non-confrontational approaches when responding to bullying (Dawes et al., 2023).

In contrast, teachers often adopt more than one approach, combining discipline and adult intervention for bullies with emotional support for victims (Yoon, Sulkowski and Bauman, 2016). An authoritarian attitude appears to be predicted only by the year of study. This approach externalizes intervention in bullying situations and tends to attribute the solution to authority figures, institutional structures, and school administration rather than individual action. As a result, it stands in contrast to other subdimensions that emphasise active individual involvement and instead reflect a more passive orientation. One of the main reasons for this is that "even though they accept that bullying is unacceptable, they do not know exactly how to deal with it, which may lead them to encourage others to take responsibility for the intervention" to change the situation (Begotti, Tirassa and Acquadro Maran, 2017: 178). They may also need the help of the system, school, or institution to increase effectiveness and prefer collaboration with others directly or indirectly involved in the education system (Beran, 2005; Craig, Bell and Leschied, 2011). It should be noted that, as in many other countries, teacher candidates in Hungary do not receive any formal courses on bullying or behaviour management, and their thoughts and future behaviours regarding this incident are often shaped by teaching practice, role models, their experience, or teachers' personal beliefs. Therefore, determining and shaping the attitudes that form the basis of behaviour before graduation may positively affect candidates' approach to bullying once they begin their careers.

Limitations and Future Research Suggestions

Although the study yields interesting results, it has some limitations. Firstly, the focus group of the study consists of the PETC. This limitation may limit the generalisability of the study to other teaching disciplines, countries, and cultures. Although the number of participants is sufficient for the analysis, working with larger and more diverse samples to make stronger inferences may provide stronger evidence about the effect of responsibility on attitudes. Similarly, the fact that attitudes and responsibilities are based on self-reports may have introduced some bias, causing individuals to answer differently than they actually felt. Despite the limitations mentioned above, it is an undeniable fact that the sense of responsibility influences awareness or reactions to bullying. Witnessing or experiencing serious situations where people may be harmed, such as bullying, may affect the tendency to intervene. Therefore, a longitudinal study design can be designed for future studies on attitudes and responsibility to examine their changes over time and the effects of these factors.

CONCLUSIONS

In conclusion, this study served as an important attempt to explore the potential influencing factors of PR or SR on PETC's attitudes toward bullying and to gain insight into their effects. When we evaluated these findings, we discovered that SR has a significant and strong predictive effect on PETC's attitudes towards bullying, specifically in the areas of Ignore, Humanistic, Tough, and overall attitudes. It is believed that understanding the factors underlying the formation of beliefs and attitudes of PETC towards bullying will provide new opportunities, particularly for policymakers and educational institutions. This is consistent with Nickerson et al. (2024: 5), who argue that *"responsibility is a key element of overcoming some of the barriers to taking action to help in the situation"*. The current study suggests that policymakers, teacher educators, and anti-bullying programs should consider the possible contributions of candidate-related attitudes, beliefs, values, and emotions to combating bullying, as well as their connection to personal, social, or professional responsibility. Together with their professional and pedagogical training, these elements can be shaped within the framework of educational accountability, paving the way for future educators to take responsibility for their choices, take action when needed, and develop a solution-oriented approach.

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Full research paper

PREDICTING UNIVERSITY ENGAGEMENT OF PHYSICAL EDUCATION TEACHER EDUCATION (PETE) STUDENTS VIA THREE POSITIVE TRAITS: LIFE SATISFACTION, ACADEMIC RESILIENCE, AND CURIOSITY

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ABSTRACT

Previous studies have examined life satisfaction, academic resilience, and curiosity as individual predictors of student engagement. Yet, limited evidence addresses how these traits collectively relate to university engagement, particularly among Physical Education Teacher Education (PETE) students. This study investigated the predictive roles of life satisfaction (LS), academic resilience (ARS), and curiosity and exploration (CUR) in relation to university engagement (UE) and its three dimensions: vigor (VI), dedication (DE), and absorption (ABS). A sample of 2,730 PETE students from higher education institutions across the Philippines participated, and regression analyses were conducted. Results showed that curiosity consistently demonstrated significant associations with overall university engagement and each dimension. Academic resilience related only to dedication, while life satisfaction revealed no significant links with any domain. These findings suggest that while LS and ARS may support broader well-being, curiosity is more directly tied to participation, emotional commitment, and cognitive immersion in university life. For PETE students, whose engagement spans academic and performance demands, cultivating curiosity may be vital. The study highlights the importance of fostering learning environments that encourage exploration and openness, thereby strengthening engagement and better preparing future educators to navigate the complexities of teaching and lifelong professional growth.

KEYWORDS

Academic resilience, curiosity, education policy, life satisfaction, physical education, teacher education

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Highlights

- *Life satisfaction, academic resilience, and curiosity are significantly and positively associated with the university engagement of PETE students.*
- *Among the three positive traits, curiosity emerged as the most consistent predictor across all components of engagement.*
- *Despite high R^2 values, individual trait associations with subdimensions of engagement (vigor, dedication, absorption) varied, emphasizing the multidimensional nature of student motivation.*
- *Findings underscore the importance of fostering curiosity-driven learning environments in PE teacher education to optimize engagement and support long-term academic resilience.*

INTRODUCTION

Numerous scholarly investigations have consistently highlighted the role of three positive psychological traits, such as life satisfaction, academic resilience, and curiosity, in fostering student engagement and academic performance (Antaramian, 2017; Burgos-Videla et al., 2022; Martin et al., 2022; Oliveira and Lathrop, 2022). Within the domains of educational and positive psychology, growing scholarly interest has been directed toward these constructs due to their individual contributions to students' well-being and academic success (Kashdan et al., 2009; Veenhoven, 2015; Vidler, 1980). While substantial empirical research has examined these traits separately, there is limited evidence assessing their combined associations with university engagement. Moreover, few studies have explored how these positive traits relate to the specific components of university engagement (*vigor, dedication*, and *absorption*), particularly in the context of Philippine higher education. To address this gap, this study investigated the joint and individual associations of these three positive traits — life satisfaction, academic resilience, and curiosity —with university engagement among PETE students.

Theoretical Foundations of University Engagement and Positive Psychological Traits

Conceptualizing University Engagement

University engagement has emerged as a central construct in educational psychology, valued for its potential to predict student success and academic persistence (Liu et al., 2021). Engagement reflects the degree to which students are mentally, emotionally, and behaviorally invested in their learning processes. It manifests in behaviors such as attentiveness, curiosity, sustained effort, and emotional involvement with academic content (Charkhabi et al., 2019). Scholars have widely accepted that engagement operates across three interconnected domains: cognitive, affective, and behavioral (da Fonseca, Santos, and Santos, 2023; de Toro et al., 2023).
These domains are operationalized and contextualized through three core dimensions (Jaya and Ariyanto, 2021): *vigor* (VI), referring to energy and resilience in academic tasks (Demirbatır, 2020; Pulido-Martos et al., 2020); *dedication* (DE), which reflects a sense of purpose, enthusiasm and pride in one's studies (Listau, Christensen and Innstrand, 2017; Teuber, Nussbeck and Wild, 2021); and *absorption* (ABS), characterized by deep immersion and focus during learning activities (Dacillo et al., 2022). These dimensions form the foundation of the Utrecht Work Engagement Scale for Students (UWES-9S) by Carmona-Halty, Schaufeli, and Salanova (2019), which has been used in numerous studies to examine the correlation between engagement and various academic outcomes. A growing body of research confirms that higher engagement is consistently linked to improved academic achievement across diverse populations and learning contexts (Acosta-Gonzaga, 2023; Luo et al., 2023).

Life Satisfaction as a Psychological Resource

Life satisfaction, a key indicator of subjective well-being, refers to a person's overall evaluation of their quality of life according to self-defined standards (Gazi et al., 2025; Shin and Johnson, 1978; Veenhoven, 2015). It encompasses both emotional and cognitive appraisals of life circumstances and is closely related to an individual's perception of meaning, fulfillment, and psychological balance (Ellison, Gay, and Glass, 1989; Usán Supervía, Salavera Bordás, and Murillo Lorente, 2020). Suikkanen's (2011) rational life satisfaction theory posits that individuals evaluate their lives based not only on present feelings but also on how closely their actual experiences align with an idealized life trajectory shaped by rational self-reflection. In the academic context, life satisfaction has been linked to a range of adaptive outcomes, including increased motivation, enhanced emotional regulation, and greater resilience (Zhang et al., 2023). While primarily studied in relation to general well-being, emerging studies suggest that students who report high levels of life satisfaction tend to demonstrate greater engagement in academic activities. Longitudinal and cross-cultural investigations have consistently found that students who are content with their lives are more likely to be immersed in learning, persist through challenges, and derive meaning from school-related experiences (Rainey, 2017; Upadyaya and Salmela-Aro, 2017; Yuen, 2016).

Academic resilience and the capacity to engage

Academic resilience refers to a student's ability to adapt to and recover from significant academic setbacks or stressors (Ang et al., 2022; Van Breda, 2018). Grounded in resilience theory, it encompasses personal traits (e.g., perseverance, motivation), social support systems (e.g., relationships with teachers), and contextual factors (e.g., school climate) that help students cope effectively with adversity (Hartling, 2008; Hechanova et al., 2023). In educational settings, academic resilience has been viewed as both a protective factor and a developmental competency. Students with higher resilience are more likely to remain engaged despite academic pressures, perform well, and avoid disengagement or dropout (Fiorilli et al., 2020; García-Crespo, Fernández-Alonso, and Muñiz, 2021). Recent studies have explored how resilient students utilize support systems, regulate their emotions, and sustain their involvement in learning activities, even in challenging conditions (García-Crespo et al., 2021; Lohner & Aprea, 2021). Although some research presents mixed results regarding the strength of the relationship between resilience and engagement (Rodríguez-Fernández, Ramos-Díaz, and Axpe-Saez, 2018), many scholars argue that academic resilience can reinforce students' persistence and commitment to academic tasks (Ahmed et al., 2018; Lobo, 2023; Tortosa Martínez, Pérez-Fuentes, and Molero Jurado, 2023).

Curiosity and the drive to explore

Curiosity is widely recognized as a core driver of intrinsic motivation and learning engagement (Kashdan et al., 2009; Spitzer et al., 2023). It entails the active pursuit of novel information and experiences, reflecting a psychological readiness to explore ambiguity and uncertainty (Chang, Shih, and Lin, 2023; Jirout, 2020). Curiosity is not merely an emotional impulse. It is also a cognitive and behavioral tendency associated with personal growth, academic achievement, and adaptability (Ernst and Burcak, 2019; Evans et al., 2023). Kashdan et al. (2009) distinguish between two components of curiosity: *stretching*, which involves the active seeking of new knowledge and challenges (Fry, Elkins, and Farrell, 2023), and *embracing*, which is the willingness to accept and navigate uncertainty (Devereux, 2022). These components are crucial in fostering sustained engagement, particularly in educational environments that demand critical thinking, creativity, and openness to change (Berlyne, 1960;

Deci, 1975; Litman, 2019). Several recent studies have shown that learners with high levels of curiosity are more likely to engage meaningfully with academic content, demonstrate persistence in problem-solving, and perform better in cognitive tasks (Mahama, Yusuf Dramanu, and Asamoah-Gyimah, 2023; Schutte and Malouff, 2022). Moreover, curiosity has been positively associated with both emotional engagement and deep learning strategies, positioning it as a vital resource for academic success (Singh and Manjaly, 2022; Whitecross and Smithson, 2023).

Objectives of the study and hypotheses formulation

This study investigated the association between three positive psychological traits—life satisfaction (LS), academic resilience (ARS), and curiosity and exploration, comprising stretching (STR) and embracing (EMB) —and University Engagement (UE) among PETE students in the Philippine higher education context. Specifically, it examined the joint and individual associations of these traits with overall UE and its three subcomponents: vigor (VI), dedication (DE), and absorption (ABS). The following hypotheses guided the investigation:

- **H_1** to **H_5**: LS, ARS, STR, and EMB, as well as their joint construct, were each positively associated with UE
- **H_6** to **H_{10}**: LS, ARS, STR, and EMB, and their joint construct was each positively associated with VI
- **H_{11}** to **H_{15}**: LS, ARS, STR, and EMB, and their joint construct was each positively associated with DE
- **H_{16}** to **H_{20}**: LS, ARS, STR, and EMB, and their joint construct was each positively associated with ABS

METHODS AND MATERIALS

Participants and Sampling Technique

This study involved undergraduate students enrolled in the Physical Education Teacher Education (PETE) program from multiple higher education institutions in the Philippines. A combination of *purposive* and *convenience* sampling was employed to recruit participants who met specific eligibility criteria: (1) current enrollment in any teacher education specialization, (2) aged 19 years and above, and (3) identifying as either male or female. These techniques allowed for efficient access to participants who could provide relevant and meaningful responses (Bhardwaj, 2019; Frey, 2018). Data collection was conducted from February to April 2022. A total of 2,730 valid responses were obtained and retained for analysis after data cleaning. The demographic characteristics of the participants are presented in Table 1.

Variables	Items	*N* (%)
Sex	Male	1031(37.8%)
	Female	1699(62.2%)
Age group	19-21 years old	2232(81.8%)
	22-24 years old	409(15.0%)
	25 years old and above	89(3.3%)
Institution	Aklan State University	432(15.8%)
	Northern Iloilo State University	365(13.4%)
	Capiz State University	430(15.8%)
	Central Luzon State University	863(31.6%)
	Mabalacat City College	296(10.8%)
	Pampanga State Agricultural University	344(12.6%)

Table 1: Demographic Profile of the respondents

Instruments and Data Gathering

Five self-report instruments were used in this study. The first section of the questionnaire collected demographic information, including sex, age group, and academic institution. All psychometric scales were administered in English, which is both the official language and primary medium of instruction in Philippine higher education. Therefore, no translation or cultural adaptation was further performed.

To assess life satisfaction, the Satisfaction with Life Scale (SwLS) by Diener et al. (1985) was adopted. This 5-item scale uses a 7-point Likert format ranging from 1 ("strongly disagree") to 7 ("strongly agree"), with higher scores indicating greater life satisfaction. A sample item includes: "The conditions of my life are excellent." Furthermore, to measure trait curiosity, the Curiosity and Exploration Inventory-II by Kashdan et al. (2009) was employed. This 10-item instrument is divided into two subdimensions: Stretching (e.g., "I am at my best when doing something complex or challenging") and Embracing (e.g., "Everywhere I go, I am out looking for new things or experiences"), rated on a 5-point Likert scale from 1 ("very slightly or not at all") to 5 ("extremely"). Moreover, academic resilience was measured using the Academic Resilience Scale (ARS-30) developed by Cassidy (2016). This 30-item instrument assesses cognitive, affective, and behavioral responses to academic challenges. Items (e.g., "I would start to monitor and evaluate my achievements and effort") are scored on a 5-point Likert scale ranging from 1 ("unlikely") to 5 ("likely"). Lastly, university engagement was assessed through the Utrecht Work Engagement Scale for Students (UWES-9S) by Carmona-Halty et al. (2019). This 9-item tool measures three dimensions: vigor (e.g., "I feel energetic and capable when I'm studying or going to class"), dedication (e.g., "I am proud of my studies") and absorption (e.g., "I feel happy when I am studying immensely"), rated from 0 ("never") to 6 ("always"). For all instruments, composite scores were computed by summing item responses. Higher composite scores represent higher levels of the respective constructs.

Data analysis

A normality and reliability test was first performed on all the variables being examined. Based on the findings, most of the scales obtained the threshold value of -2 to 2. In this regard, it can be determined that the data are normally distributed [SwL (5.45 ± 1.35; *Skew* = -1.134 *Kurt* = 1.002), ARS (3.61 ± .38; *Skew* = .582 *Kurt* = 3.258), curiosity and exploration: STR (4.19 ± .83; *Skew* = -1.890 *Kurt* = 3.913), EMB (4.07 ± .75; *Skew* = -1.561 *Kurt* = 3.000), UE (4.09 ±.76; *Skew* = -1.659 *Kurt* = 3.258), VI (4.06 ± .75; *Skew* = -1.315 *Kurt* = 2.006), DE (4.31 ± .83; *Skew* = -1.970 *Kurt* = 4.082), and ABS (3.89 ± .78; *Skew* = - .986 *Kurt* = .1234)]. Furthermore, the reliability test has shown that all scales obtained high reliability scores [SwL (α ≈ .93), ARS (α ≈ .81), Curiosity and Exploration: STR (α ≈ .93), EMB (α ≈ .89), UE (α ≈ .95), VI (α ≈ .87), DE (α ≈ .90), and ABS (α ≈ .84)]. Lastly, a series of *multiple regression analysis* was performed. This form of modeling involves predicting a target variable by utilizing data derived from multiple predictors (Li et al., 2022). In the present analysis, the present study has three predicting variables. The objective is to explore the association of these predictors with university engagement. Finally, the three aforementioned predictor variables will be analyzed as a single model to assess their influence on the three separate dimensions of UE.

Ethical Statement

The respondents were provided with information regarding the objectives of the research, as well as the particular measurements and factors that were of importance. The researchers have additionally communicated the study's implications to the various universities and the broader scientific community. The participants indicated their consent by selecting an integrated agreement option within the Google Forms. Additionally, they were provided with the opportunity to choose whether or not to participate. The potential for respondents to experience discomfort when answering personal and sensitive survey questions was also identified as a minor risk that participants should consider before consenting to participate in the study. Respondents were allowed to withdraw or receive debriefing at any point, according to these restrictions.

RESULTS

The regression analysis showed that the combination of LS, ARS, STR, and EMB significantly predicted overall UE [$F(4, 2725) = 149{,}061.180$, $p < .001$]. The model accounted for 99.5% of the variance ($R^2 = .995$). Among the predictors, STR ($\beta = .431$, $t = 142.723$, $p < .001$) and EMB ($\beta = .567$, $t = 169.676$, $p < .001$) were positively and significantly associated with UE. In contrast, LS ($\beta = -.001$, $t = -.851$, $p = .395$) and ARS ($\beta = -.005$, $t = -1.783$, $p = .075$) were not significant.

For VI, the model remained significant [$F(4, 2725) = 10{,}083.833$, $p < .001$], explaining 93.7% of the variance ($R^2 = .937$). Both STR ($\beta = .158$, $t = 12.934$, $p < .001$) and EMB ($\beta = .911$, $t = 67.551$, $p < .001$) significantly predicted VI, while LS ($\beta = .002$, $t = .654$, $p = .513$) and ARS ($\beta = .010$, $t = .947$, $p = .344$) did not. A similar pattern emerged in the DE model [$F(4, 2725) = 6{,}496.695$, $p < .001$], explaining 90.5% of the variance ($R^2 = .905$). Both STR ($\beta = .647$, $t = 43.446$, $p < .001$) and EMB ($\beta = .357$, $t = 21.631$, $p < .001$) remained significant predictors. Interestingly, ARS ($\beta = -.027$, $t = -2.115$, $p = .035$) was also significant but negatively associated, while LS ($\beta = .001$, $t = .188$, $p = .851$) remained non-significant. For ABS, the model was also significant [$F(4, 2725) = 3{,}339.627$, $p < .001$], explaining 90.5% of the variance ($R^2 = .905$). Both STR ($\beta = .488$, $t = 25.935$, $p < .001$) and EMB ($\beta = .433$, $t = 20.801$, $p < .001$) significantly predicted ABS. LS ($\beta = -.004$, $t = -.982$, $p = .326$) and ARS ($\beta = .031$, $t = 1.919$, $p = .055$) again showed no significant association. Across all models, STR and EMB consistently emerged as the strongest predictors of UE and its components (VI, DE, ABS). At the same time, LS and ARS showed limited or no significant direct associations, as can be seen in Table 2.

DISCUSSION

This study examined the associations between life satisfaction, academic resilience, curiosity, and exploration and university engagement among PETE students. The regression analyses revealed that while all three constructs contributed to the overall model, only curiosity consistently showed significant and positive associations with the university engagement of PETE students and its subcomponents. In contrast, life satisfaction and academic resilience demonstrated minimal or inconsistent associations with engagement, suggesting the primacy of curiosity-driven dispositions in sustaining PETE students' academic involvement.

The absence of a significant association between life satisfaction and university engagement diverges from earlier empirical assertions that students who are satisfied with their lives are more likely to invest effort and energy in academic activities (Rainey, 2017; Upadyaya and Salmela-Aro, 2017; Yuen, 2016). While these prior studies emphasize a reciprocal dynamic between well-being and engagement, the present findings highlight a more nuanced picture. Life satisfaction is often considered a global and subjective assessment of one's quality of life (Shin and Johnson, 1978; Zhou and Lin, 2016), which may not directly translate to daily academic behaviors. It is plausible that students may perceive their lives as fulfilling without necessarily feeling compelled to participate vigorously in university tasks. Factors external to the academic domain (i.e., family life, friendships, or spirituality) could shape their sense of satisfaction, thereby diluting any direct connection to academic engagement (Amati et al., 2018; David et al., 2022; Vautero et al., 2021). This highlights the importance of considering life satisfaction as a distinct dimension of psychological well-being that may not always align with students' academic motivations or investments.

Similarly, the limited associations observed between academic resilience and university engagement call for critical reflection. While academic resilience has often been described as a protective factor that enables students to recover from setbacks and maintain goal-directed behavior (Allan, McKenna, and Dominey, 2014; Fiorilli et al., 2020; Martin, 2013), the current findings suggest that such resilience may not necessarily foster higher levels of engagement across all contexts. Interestingly, while academic resilience showed a modest negative association with dedication, it was not a consistent predictor of vigor or

Hypothesis	Regression weights	Beta Coefficient	R^2	F	t	p	Decision
H_1	LS+ARS+STR+EMB → UE	-	.995	149061.180	-	< .001	Accepted
H_2	LS → UE	- .001	-	-	- .851	.395	Rejected
H_3	ARS → UE	.005	-	-	1.783	.075	Rejected
H_4	STR → UE	.431	-	-	142.723	< .001	Accepted
H_5	EMB → UE	.567	-	-	169.676	< .001	Accepted
H_6	LS+ARS+STR+EMB → VI	-	.937	10083.833	-	< .001	Accepted
H_7	LS → VI	.002	-	-	.654	.513	Rejected
H_8	ARS → VI	.010	-	-	.947	.344	Rejected
H_9	STR → VI	.158	-	-	12.934	< .001	Accepted
H_{10}	EMB → VI	.911	-	-	67.551	< .001	Accepted
H_{11}	LS+ARS+STR+EMB → DE	-	.905	-	6496.695	< .001	Accepted
H_{12}	LS → DE	.001	-	-	.188	.851	Rejected
H_{13}	ARS → DE	- .027	-	-	-2.115	.035	Accepted
H_{14}	STR → DE	.647	-	-	43.446	< .001	Accepted
H_{15}	EMB → DE	.357	-	-	21.631	< .001	Accepted
H_{16}	LS+ARS+STR+EMB → DE	-	.905	3339.627	-	< .001	Accepted
H_{17}	LS → ABS	- .004	-	-	- .982	.326	Rejected
H_{18}	ARS → ABS	.031	-	-	1.919	.055	Rejected
H_{19}	STR → ABS	.488	-	-	25.935	< .001	Accepted
H_{20}	EMB → ABS	.433	-	-	20.801	< .001	Accepted

Legend: LS- Life Satisfaction, ARS- Academic Resilience, Curiosity and Exploration (STR- Stretching, EMB- Embracing), UE- University Engagement (VI- Vigor, DE- Dedication, ABS- Absorption)

Table 2: Predicting university engagement and subdimensions from life satisfaction, academic resilience, and curiosity constructs: Summary of regression models

absorption. This could indicate that resilience operates more as a reactive capacity (activated during adversity), rather than as a day-to-day driver of motivation or focus. Students may possess strong coping skills but still exhibit disengagement if the learning environment lacks challenge, relevance, or emotional support. Moreover, the educational climate in which students operate may either activate or suppress the expression of resilient behaviors (Lacoe, 2020; Thapa et al., 2013). This aligns with the view that resilience is context-sensitive and may require the presence of adversity or meaningful goals to manifest as sustained academic energy (Riley and Masten, 2005).

On the other hand, the role of curiosity and exploration emerged as central in understanding students' engagement with university life. Both stretching and embracing were strongly and positively associated with all three dimensions of university engagement. These findings affirm the theoretical argument that curiosity is a fundamental psychological resource that promotes sustained academic involvement (Fry et al., 2023; Schutte and Malouff, 2022). Students who actively seek novel information and show a willingness to engage with complexity are more likely to experience learning as a meaningful and energizing process (Lobo, 2024; Lobo et al., 2024). In contrast to resilience or life satisfaction, curiosity functions as an anticipatory trait, encouraging proactive exploration rather than simply helping students bounce back from challenges. This aligns with Dubey, Griffiths, and Lombrozo's (2022) conceptualization of curiosity as a multi-faceted driver of intellectual growth, competence development, and motivational persistence throughout the lifespan. In the university context, which often demands independent learning and abstract thinking, curiosity appears to be a particularly adaptive asset.

In sum, this study highlights the differential roles that life satisfaction, academic resilience, and curiosity and exploration play in relation to students' university engagement. Although life satisfaction and academic resilience are often emphasized in educational research as crucial psychological resources, their direct associations with vigor, dedication, and absorption appeared limited in this context. By contrast, the strong and consistent associations between curiosity-based traits and all components of engagement underscore their centrality in understanding what motivates students to meaningfully connect with academic life. These findings contribute to a more nuanced understanding of student engagement and invite further research into how these traits operate across varying learning conditions and student populations.

CONCLUSION

This study examined the relationships between life satisfaction, academic resilience, curiosity-exploration traits, and university engagement among Physical Education Teacher Education (PETE) students in the Philippines. Findings revealed that while life satisfaction and academic resilience had limited or non-significant associations with students' engagement in the university context, curiosity-related traits showed strong and consistent links with overall engagement and its subdimensions. These results suggest the importance of interest-driven and exploratory dispositions over generalized psychological well-being or adversity-coping traits in predicting engagement behaviors within the higher education landscape, particularly among pre-service physical educators.

Implications and pedagogical applications

The study has direct implications for PETE programs and teacher education pedagogy. Since curiosity showed the most robust associations with university engagement, Physical Education instruction should prioritize strategies that ignite and sustain exploratory learning. This includes incorporating movement-based inquiry, problem-solving in physical activities, gamification of fitness principles, and culturally meaningful sports and dance traditions that invite students to ask questions, try new forms, and make meaning from embodied experience.

Moreover, given that PETE students are being trained to become future educators, the development of curiosity is not only essential for their own learning but also vital for cultivating curiosity in their future learners. Therefore, teacher training curricula should model curiosity-driven instruction, encouraging reflective practice, innovation in lesson planning, and integration of learner-centered pedagogies. This aligns with the growing emphasis on 21st-century teaching competencies that extend beyond content delivery to promote critical thinking, adaptability, and lifelong learning.

It also invites institutions to critically assess the limitations of purely resilience-based or wellness-centered interventions, which, while important, may not directly foster classroom engagement or teaching motivation. Instead, institutions should consider designing professional growth experiences that position curiosity as a pedagogical asset, especially in dynamic disciplines like physical education, where creativity, flexibility, and exploratory teaching are central.

Limitations of the study

Despite its meaningful contributions, this study acknowledges several limitations. First, data were obtained through self-reported instruments, which are susceptible to biases such as social desirability, overreporting of engagement, or misinterpretation of survey items. Second, all psychological and engagement-related constructs were analyzed as composite scores, which, while statistically efficient, may mask finer variations and multidimensional nuances within each construct. Third, although the study yielded relatively high R^2 values, this should be interpreted cautiously. The strength of these predictive relationships, while encouraging, may partly reflect contextual or methodological artifacts. Specifically, the lack of construct revalidation for the Filipino PETE population means that instrument sensitivity and cultural alignment could have influenced the precision of measurement and inflated explained variance estimates. Fourth, the cross-sectional nature of the design prohibits any conclusions about temporal dynamics or developmental progression. Engagement and psychological traits may evolve significantly over the course of a PETE student's academic journey, particularly during transitions from theoretical coursework to a field-based teaching practicum. Therefore, a snapshot view limits the generalizability of associations over time. Fifth, while the sample size was statistically robust and drawn from multiple institutions, it may still fall short of representing the full heterogeneity of PETE learners across the country, especially those from geographically isolated or resource-deprived institutions. Lastly, the study centered solely on intra-individual psychological traits, excluding critical contextual variables such as instructional quality, peer collaboration, institutional support systems, and access to physical activity spaces, all of which may significantly influence student engagement in physical education contexts. These limitations provide valuable guidance for refining future inquiries and temper the interpretation of the high predictive capacity suggested by the model.

Future research directions

Future studies are encouraged to examine how contextual and environmental variables interact with individual traits to shape engagement in PETE programs. Mixed-methods designs could enrich understanding by capturing the voices of students in naturalistic teaching and learning settings. Longitudinal studies would also help track how curiosity and engagement evolve across the teacher education journey, from coursework to field experiences and internship placements. Further validation of curiosity constructs within the PE and Filipino cultural context is warranted, especially in ensuring semantic alignment of terms like “embracing uncertainty” or “stretching knowledge” when applied to embodied learning. Exploring the impact of teacher modeling, learning climate, and curriculum design on the development of curiosity in PE settings could also provide important pedagogical insights. Comparative studies across academic disciplines might also help determine whether the strength of associations found here is unique to PETE or generalizable to other professional programs.

Contribution to global discourse

This study contributes to global conversations on student engagement by highlighting the critical role of curiosity in shaping the academic vitality of future educators. Examining PETE students in a Global South context adds empirical weight to the argument that fostering intellectual exploration and openness may be more effective in stimulating meaningful academic participation than relying solely on well-being or adversity-based constructs. Moreover, the findings encourage rethinking how institutions support teacher candidates, not merely through resilience-building but by fostering cognitive-affective dispositions that are more directly aligned with sustained engagement and pedagogical creativity. This opens new dialogues on interest development, embodied curiosity, and motivation in movement-based education, expanding the global framework of student engagement to include culturally grounded, discipline-specific, and curiosity-informed perspectives.

DECLARATIONS

Conflict of Interest

The contributors hereby certify that there are no conflicts of interest.

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Data and Materials

Access to materials and data will be provided exclusively upon request.

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Full research paper

ENHANCING PRE-SERVICE MATHEMATICS TEACHERS' PROOF-WRITING SKILLS: THE EFFECT OF A SOCIAL LEARNING ENVIRONMENT ENRICHED WITH DYNAMIC GEOMETRY SOFTWARE

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ABSTRACT

Mathematical proof, often regarded as the heart of mathematics, is essential for interconnected mathematical knowledge. However, proof-writing skills do not develop inherently. Effective learning environments are vital for university students to enhance these skills. This study investigates the impact of the ISMAT model on pre-service teachers' proof-writing skills. The model, based on quasi-experimental paradigms and arguments from Popper (1979) and Lakatos (1961, 1976), utilizes dynamic geometry software to enhance the understanding of proof functions. It is hypothesized that a social learning environment, augmented by dynamic geometry, will yield observable effects. The research employed a quasi-experimental design with experimental and control groups of pre-service mathematics teachers. The experimental group received 14 weeks of Euclidean geometry lessons using the ISMAT model, while the control group followed traditional methods. Data were collected through proof-writing tests administered pre- and post-instruction. The evaluations were conducted using Senk's (1983) framework for assessing proof-writing skills. Results indicated that the ISMAT model significantly enhanced proof-writing skills compared to traditional teaching methods. Such approaches are recommended to foster active student engagement in the proving process.

KEYWORDS

Instructional model, proof teaching, reasoning

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Highlights

- *The ISMAT Model underpins the design of proof-writing teaching environments.*
- *The model integrates social dimensions, proof functions, and reasoning types.*
- *The model is adaptable to various educational levels for proof-writing teaching.*
- *A social learning environment enhanced with dynamic geometry software effectively enhances proof-writing skills.*

INTRODUCTION

The advancement of mathematical knowledge requires geometry to improve deductive reasoning (González & Herbst, 2006). Proofs are crucial for conveying essential mathematical concepts (Hanna & Barbeau, 2010). Therefore, proofs are fundamental to the essence of mathematics (Ross, 1998), and the discipline is fundamentally about proof-writing (Heintz, 2000). As a result, the development of proof skills is crucial in Turkey's mathematics and geometry education, alongside skills such as data reasoning and problem-solving (MEB, 2013; Nasibov & Kaçar, 2005; Toluk, 2003). In school mathematics, the main goals of proof include fostering explanation, insight, and deep understanding (e.g., Dickerson & Doerr, 2014; Hanna, 2000; Stylianides, 2009; Yackel & Hanna, 2003). Thus, proof-writing is a fundamental aspect of mathematics teaching. Proof is essential in mathematics for disseminating and comprehending knowledge (Dolev & Elen, 2013; Ozturk, 2016; Mariotti, 2006). It serves to validate statements and reveal fundamental truths (Stylianou, Blanton & Knuth, 2009; Hanna, 2000). Additionally, proof incorporates a social aspect, involving mental activities like conjecturing and logical deduction (Hanna, 1991; Greenberg, 1993). Despite its significance in education, research shows students encounter notable challenges with mathematical proof at various educational levels (Heinze et al., 2008; Hoyles & Küchemann, 2002; Knuth, Choppin & Bieda, 2009; Stylianides & Stylianides, 2017). These challenges encompass a lack of initiation knowledge, misinterpretation of the necessity of techniques, and the perception of proofs as superfluous (Weber, 2001; Burgett, 2018; Buchbinder & McCrone, 2020). Furthermore, the perceived simplicity of proofs is exacerbated by non-collaborative activities, which are vital for the proving process (Cilli-Turner, 2017; Grundmeier et al., 2022; Melhuish et al., 2022; Yoo & Smith, 2007). Students' engagement with proof frequently remains static despite the implementation of diverse pedagogical approaches aimed at mitigating these challenges (Bermudez & Graysay, 2025; Ndemo, Mtetwa & Zindi, 2019).

This research focuses on the social dimensions inherent in the construction of mathematical knowledge, the functions of proof, and how a pedagogical approach involving the integration of dynamic geometry software into the learning environment affects pre-service teachers' skills in writing mathematical proofs.

Theoretical Background

Proof enhances mathematical knowledge and understanding (Hanna & Barbeau, 2010). Recognizing connections and comprehending mathematical thought are essential for proof (Flores, 2002). Forman et al. (1998) emphasize the importance of proof-writing in developing mathematical language. Proof distinguishes mathematical statements from other ideas, conferring significance (Hersh, 2009). However, proof involves exploration, conjecturing, reasoning, and argument formulation (Hanna et al., 2004; Pedemonte & Reid, 2011; Remillard, 2009; Stylianides & Ball, 2008). Researchers contend that proof fulfills various functions beyond verification in mathematics education (Almeida, 2003; Bell, 1976; De Villiers, 1990; Hanna & Jahnke, 1996; Hanna, Jahnke & Pulte, 2010). De Villiers (1990) builds on Bell's (1976) functions of proof, adding discovery and communication. The functions of proof encompass verification, explanation, systematization, discovery, and communication. De Villiers (1999) argues that proof presents an intellectual challenge, thus adding this function. Consequently, proof involves investigating mathematical phenomena through pattern recognition, conjecturing, and argumentation (Stylianides, 2008). In mathematics education, proof significantly contributes to the augmentation of mathematical proficiency and logical reasoning (Hanna, 2000).

Challenges in the Proving Process

Proof is fundamental for mathematical comprehension and communication (e.g., Ball & Bass, 2003; Hanna Larvor & Yan, 2023; Herbst & Brach, 2006). However, the significance of proof in fostering mathematical thought is often underestimated. Consequently, proof-writing presents challenges for students at all academic levels (e.g., Jones & Herbst, 2012; Stylianides & Stylianides, 2017; Stylianou, Blanton & Knuth, 2009). Numerous studies identify various factors contributing to difficulties in proof-writing (e.g., Chazan, 1993; Harel & Fuller, 2009; Harel & Sowder, 2007; Moore, 1994; Selden & Selden, 2007; Weber, 2006). Moore (1994) delineates key sources of students' challenges in proof-writing, including perceptions of mathematics and proof, conceptual understanding, mathematical language, and initiation of proof. Harel and Sowder (2007) emphasize the role of cognitive factors in shaping students' engagement with proof. They assert that multiple influences, such as students' or teachers' attitudes towards proof and the design of the learning environment, affect students' proof-related behaviors, necessitating a multifaceted approach to understanding their difficulties. This indicates that an array of factors impacts the proving process. Therefore, a thorough understanding of the obstacles in proof-writing is imperative. Moreover, it is crucial to create educational settings that facilitate proof-writing and to employ pedagogical strategies that reflect the intrinsic nature of proof and encourage student involvement in proof activities.

Proof-Writing Skill

Proof is a comprehensive process reliant on visual or experimental evidence, logical reasoning, and personal convictions (Hoyles & Healy, 2007). Proof-writing is not merely about demonstrating mathematical truth; it embodies a cognitive framework. This is supported by Ball et al. (2002), who argue that it involves cognitive habits like identifying constructs, exploring, formulating assumptions, and organizing reasoning. Greenberg (1993) further substantiates this by noting that writing proofs includes various cognitive activities such as generating assumptions and deriving logical conclusions. Thus, proof-writing is a significant task that requires a wide range of skills, including reasoning and problem-solving, which enhance mathematical cognition. Therefore, instructional methods that encompass diverse skills and recognize the essence of proof are linked to improved proof-writing skills among students. This is echoed by Senk (1983), who attributed proof-writing difficulties to the characteristics of the mathematical system, cognitive development stages, and the pedagogical approaches employed. Furthermore, Senk's consideration of reasoning, justification, and mathematical language in her research on proof-writing and geometry comprehension highlights the complexity inherent in the proving process. As such, the critical actions in writing proofs and the identification of instructional methods as factors in these challenges emphasize the necessity for learning environments that align with the intrinsic nature of the proving process.

In academic research examining proof-writing (e.g., Ko & Knuth, 2009; Moore, 2016; Senk, 1983; Stylianides & Stylianides, 2009; Winer & Battista, 2022), qualitative analyses focus on essential criteria for validating an argument as a legitimate proof. Notably, reasoning, mathematical language, and justification are critical factors in evaluating proofs in these investigations. The five-level scoring scale created by Senk (1983) systematically assesses proofs, covering these dimensions and providing scores for each criterion, thereby enhancing its value as an evaluative instrument. This framework increases its efficacy by promoting thorough and explicit evaluations of proofs. The scoring scale proposed by Senk (1983) is outlined below.

- 0 – Student writes nothing, writes only the given, or writes invalid or useless deductions;
- 1 – Student writes at least one valid deduction and gives a reason;
- 2 – Student shows evidence of using a chain of reasoning, either by deducing about half the proof and stopping, or by writing a "proof" that is invalid because it is based on faulty reasoning early in the steps;
- 3 – Student writes a proof in which all steps follow logically, but in which there are errors in notation, vocabulary, or names of theorems;
- 4 – Student writes a valid proof with at most one error in notation.

Instructional Approaches for Teaching Proof and Proposed Model

The primary benefit of proof in mathematics education is enhancing mathematical comprehension (Hanna & Jahnke, 1996; Hersh, 1997). Traditionally, proof serves to confirm the accuracy of mathematical statements (Avigad, 2005; De Villiers, 1990). Nevertheless, numerous researchers emphasize that proof encompasses various functions beyond mere validation in pedagogical contexts (e.g., Almeida, 2003; Bell, 1976; De Villiers, 1990; Hanna & Jahnke, 1996; Hanna, Jahnke & Pulte, 2010). These researchers identify analogous functions associated with the mathematical significance of proof. De Villiers (1999) elaborates on Bell's (1976) framework by incorporating discovery, communication, and intellectual challenge as additional dimensions of proof. Stylianides (2009) corroborates this diversity of functions, indicating that mathematical proof involves actions such as generalizing patterns, formulating conjectures, constructing arguments, assessing others' conjectures or arguments, and disseminating mathematical knowledge. Therefore, it is crucial to adopt proof teaching methods that align with the nature of proof and encourage student engagement in proof activities. Furthermore, it is imperative to foster learning environments conducive to proof teaching that enable students to engage with the procedural steps similar to those undertaken by mathematicians during the proving process.

In undergraduate mathematics, proof teaching follows a standard deductive sequence of definition, theorem, and proof (Almeida, 2000). Moreover, proofs are presented solely as final products, depriving students of practical proof experiences (Alibert & Thomas, 1991; Ferrari, 2004). Consequently, this methodology results in a deficient comprehension of mathematical proof among students (Knuth & Elliot, 1997). Therefore, pre-service mathematics teachers should be immersed in environments where the concept of proof is emphasized, enabling them to engage in the process of proving. Enhancing their skill in this area will empower them to mentor students based on personal experiences. Consequently, acknowledging the increasing importance of proof within the realm of mathematics and its educational practices, reformulating instructional methodologies is essential.

In the domain of proof teaching literature, numerous studies focus on the enhancement of proof-writing skills (Bobango, 1987; Cook-Box, 1996; Generazzo, 2011; Hart, 1986; Hsu, 2010; Lee, 1999; Lee, 2011; Matsuda, 2004; Pulley, 2010; Senk, 1983; Sommerhoff, Kollar & Ufer, 2021; Subramanian, 1991; Tubridy, 1992). Pulley (2010) specifically investigated how non-traditional instructional activities impact students' mathematical understanding, beliefs about proof, and reasoning. The study involved students in activities that required them to create, justify, and validate proofs, resulting in advancements in geometric knowledge and reasoning. In contrast, Generazzo (2011) assessed the effects of an inquiry-based learning environment on students' skills in conjecturing, reasoning, and proof-writing through collaborative group work and discussions. Sommerhoff, Kollar, and Ufer (2021) explored the effectiveness of sequential versus concurrent instructional methods on developing mathematical argumentation and proof skills, revealing that both strategies significantly enhance foundational resources for these skills, especially for lower-performing students. The findings emphasized that interactive student activities substantially improve proof-writing and reasoning skills. Additionally, it was observed that studies assessing the effectiveness of proof teaching practices are less prevalent compared to descriptive studies on proof. Furthermore, these studies (e.g., Marrades & Gutiérrez, 2000; Selden, Selden & McKee, 2008; Smith, 2006) aim to evaluate the impact of specific teaching methods or technologies on proof-writing. In studies that define multiple steps for proof-writing, these steps are employed to facilitate various activities; however, they lack the comprehensiveness of the instructional models utilized in proof teaching. This research holds significance for three primary reasons: it offers insights for developing teaching interventions to enhance students' proof-writing skills and address cognitive challenges, it serves as a foundation for reforming proof teaching practices, and it aids in recognizing the diverse functions of proof and reshaping perceptions thereof.

Overall, the findings from these investigations suggest that alternative pedagogical approaches yield advantageous outcomes for students in the domain of proof-writing. Furthermore, they emphasize the critical role of delineating instructional models that enable learners to engage actively in the proving process. In response to the stated imperative, this study aims to propose a conceptual model that aspires to demonstrate that the proving process extends beyond the mere validation of a particular theorem; it also functions to elevate this endeavor as a substantial intellectual pursuit from the learners' perspective by promoting their involvement with the essential activities that are foundational to the nature of proof. The instructional model aims to reveal that proof-writing is not just an action to demonstrate the accuracy of a given theorem, but also to make it a meaningful process for the students by allowing them to experience the inherent stages of proof-writing. The Model includes seven stages: *understanding the problem, constructing a structure, working on the structure and conjecturing, postulation of the relationship, proving, investigating the coherence of the proof,* and *formalizing the proof.* The realization of each of the reasoning types (deduction, induction, abduction), the reflection of the functions of proof (discovery, verification, explanation, systematization,

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communication, mental challenge), the inclusion of the views of Popper (1979) and Lakatos (1961, 1976) on the knowledge formation process, and the importance of the social dimension in this process were all considered when developing the ISMAT Model stages. Popper stated that science operates in four steps: formulating a hypothesis, deducing observable and testable conclusions, testing those conclusions, and determining whether to accept or reject the proposition (Hodson, 2008). Lakatos characterised a scientific research programme as progressive and asserted that successive steps involve making testable predictions and confirming them (Worrall, 2003). This research program, especially in the context of Lakatos, was developed as a synthesis of Kuhn's and Popper's opposing views. In his book the Structure of Scientific Revolutions, Thomas Kuhn—the most significant historian and philosopher of science—presented a radically different view of science. With his book, he attempted to make sense of the assertion that scientists working under conflicting paradigms "*live in different worlds*."

Additionally, Popper (1979) emphasizes that individuals live in a mathematical world and asserts the existence of three different worlds. These three worlds are the physical, mental, and social worlds in that order. In the mental world, knowledge is derived from the individual's experiences and beliefs. It is determined in the physical world whether the subjective knowledge is applicable and if it validates individuals' experiences. In the mathematical world, individuals share their knowledge, and once that knowledge is confirmed, it becomes objective and universally accepted. Therefore, Popper and Kuhn advocate the presence of different worlds. According to Lakatos, Popper's third realm is where knowledge grows and is restructured, which highlights the same argument (Ozturk, 2016). The actions in the three worlds are compatible with the steps of the proving process. Scientists also begin their endeavours by thinking, speculating, and generating a new claim. After that, they support their arguments and produce new knowledge. Proof-writing is, obviously, a process of forming knowledge. As a result, the ISMAT Model combines the ideas of Lakatos, Popper, and Kuhn. Each of these researchers made a substantial contribution to the philosophy of science. The Model reflects how science philosophy is applied to mathematics. In other words, the Model is a reflection of the process of doing science.

In light of Stylianides's (2007) definition of the proof, Conner and Krejci (2022) assert that reasons, generality, clarity, and structure are the four essential components of proof. Since the Model includes these essential components, it serves as a representation of the proving process. Furthermore, the Model was designed to allow for both individual and group work, as well as the usage of dynamic geometry software. Nonetheless, within the parameters of the proposed model, the reciprocal exchange of proof drafts among the various groups, along with the provision for offering suggestions for amendments to the proofs, followed by a whole-class discussion regarding the proofs, is designed to facilitate the alleviation of the challenges encountered in writing proof. The stages and main principles of the ISMAT Model are presented in Figure 1.

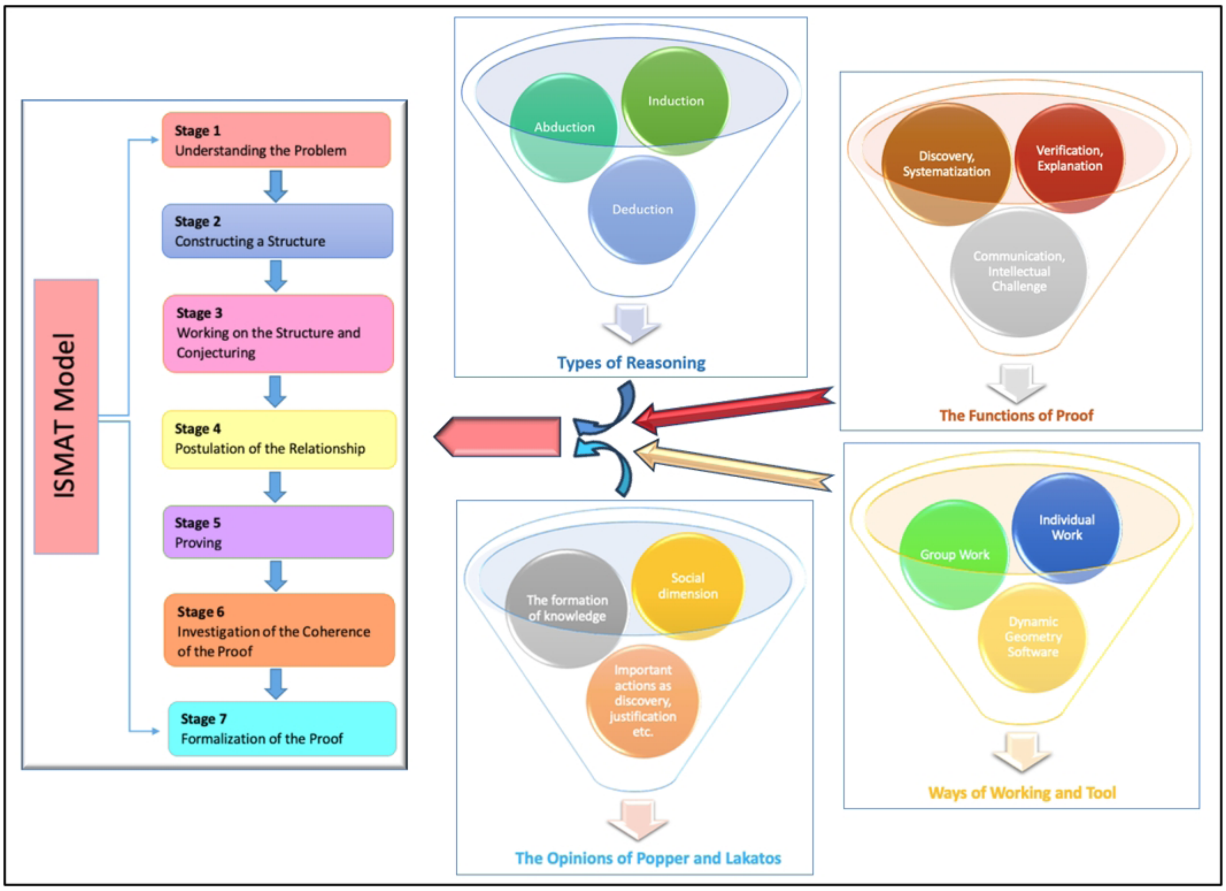


Figure 1: Stages and main principles of the ISMAT model (Ozturk, 2016)

The Purpose of the Study

Research (e.g., Moore, 1994; Stylianides, Stylianides & Shilling-Traina, 2013; Weber, 2001, 2006) indicates that students encounter considerable challenges in writing mathematical proofs in steps, even at the university level. Students exhibit notable deficiencies, particularly in employing logical connections among the steps of proof and utilizing mathematical language (Ko & Knuth, 2009; Miyazaki, Fujita, & Jones, 2016). Indeed, these deficiencies have been informally noted by the researchers of this study over an extended period, as they have been facilitating Euclidean geometry courses for numerous years. These insights significantly motivated the researchers to execute the ISMAT Model within an authentic classroom setting and to assess its outcomes. This study aimed to examine the effect of the ISMAT Model on pre-service teachers' proof-writing skills.

METHODOLOGY

Research Design

This study investigates the impact of the designed learning environment on pre-service mathematics teachers' proof-writing skills, assessing these skills both pre- and post-instruction, and analyzing the relationship between potential skill changes and the proposed model. An experimental approach was thus employed. At this point, a quasi-experimental study comparing two groups where only one is exposed to the ISMAT Model would be somewhat explanatory in terms of the proof-writing skills. However, controlling all variables except the instructional model for more than one group was quite difficult, making it challenging to draw inferences about the reasons for the change. Besides, the characteristics of the course were a threat to a quasi-experimental design due to the challenges, such as restricting communication between groups. By the way, we could apply interviews through the change, which involves obtaining quantitative data, and try to uncover the underlying reason for the change.

Participants

Every year in Turkey, students at all K–12 levels are introduced to geometry concepts before attending university. Examining the characteristics of geometric shapes and objects in middle school replaces traditional geometry teachings, which focus on identifying geometric shapes and objects, particularly in the early years of education, known as the primary school years. In the last four years, also known as high school, in addition to investigating the properties of geometric shapes and objects, elements such as proofs of basic relations and geometric drawings are included. In geometry courses, students are given exercises and problems that require the application of geometric object properties, as the Turkish educational system employs a centralized exam system for admission to reputable high schools and universities. Students cannot experience formal proof-writing activities in these courses, which are structured by centralized assessments. Students are first exposed to proofs in a formal sense in university mathematics and teaching programs, which are typically entered through central exams. As a result of the central exam, the study's sample consists of first-year students attending the mathematics teaching program at a university with a medium level of success in the central exam.

The experimental implementation of the proposed model was conducted within the scope of the "Euclidean Geometry" course, taught in the first year of the program. In this context, the study sample consisted of a total of 60 pre-service mathematics teachers, divided into two groups: 32 in the experimental group (27 girls and five boys) and 28 in the control group (15 girls and 13 boys).

This retrospective research involving human participants was in accordance with the ethical standards of the institutional and national research committees. The Social and Human Sciences Ethics Committee of Karadeniz Technical University approved this research. (Ref. No. 82554930/400-1259)

Data Collection Tool

The data were collected through a "proof-writing test" (PWT). However, upon examining the proof-writing tests, certain responses from pre-service teachers were ambiguous and lacked clarity, prompting subsequent interviews for further elucidation of their answers.

Each interview was conducted with a cohort of six pre-service teachers. The selection process for the pre-service teachers participating in the interviews was predicated on pre-test outcomes and the principle of voluntary participation. The duration of each interview was approximately 40 minutes, conducted in a setting that fostered comfort for each pre-service teacher, and incorporated various proof-writing activities. Furthermore, the interviews were administered on an individual basis to mitigate the potential for inter-participant influence among the pre-service teachers.

Proof-Writing Test

Two separate proof-writing tests were administered as both a pre-test and a post-test, preceding and succeeding the experimental intervention, to evaluate the proficiency of pre-service teachers in the domain of proof writing. Pre-service teachers were administered the Proof Writing Pre-Test (PWPRE), which comprises 12 questions, to assess their initial skills in proof-writing before the intervention. They were subsequently administered the Proof Writing Post-Test (PWPOST), also comprising 12 questions, to evaluate their proficiency following the intervention. The proof-writing questions contained within the PWPRE were meticulously designed to gauge students' existing proficiency before the intervention. They were intended to be addressed employing the foundational geometry knowledge they had amassed during their high school education. In contrast, the proof-writing questions of the PWPOST, aimed at evaluating the students' advancement post-intervention, were formulated such that they could be addressed utilizing both their high school knowledge and the newly acquired information from the Euclidean geometry course.

The initial phase in formulating the PWPRE and PWPOST tests involved selecting pertinent questions sourced from both university-level and high school textbooks, as well as from existing literature. In the process of selecting questions, consideration was given to the general high school curriculum for the pre-test and the content of the Euclidean Geometry course for the post-test, with a concerted effort made to ensure a broad scope in the coverage of the questions. To facilitate the preparation of the tests, two researchers holding doctoral degrees in mathematics education were solicited for their expert recommendations. Following revisions to the questions based on their feedback, a cohort of 45 pre-service teachers participated in a pilot implementation to assess the reception of the tests by the pre-service teacher population. Adjustments were made, and the questions were refined as a direct consequence of the pilot implementation. Following the pilot implementation, it was determined that one of the problems included in the pre-test should be substituted with an alternative problem, as it was perceived to be overly challenging for pre-service teachers who had only recently graduated from high school, thereby failing to fulfill the research objectives. In the post-test, it was considered judicious to eliminate the problem due to its requirement for direct engagement with the mathematical relationship delineated in the problems, which did not necessitate a sequence of proof steps. Nevertheless, it was deemed beneficial to incorporate a different problem into the post-test. Upon identifying that the duration allocated for completing these assessments was inadequate in the pilot implementation, it was resolved that the examination time for both assessments would be extended to 120 minutes. Figure 2 delineates the development process of the tests.

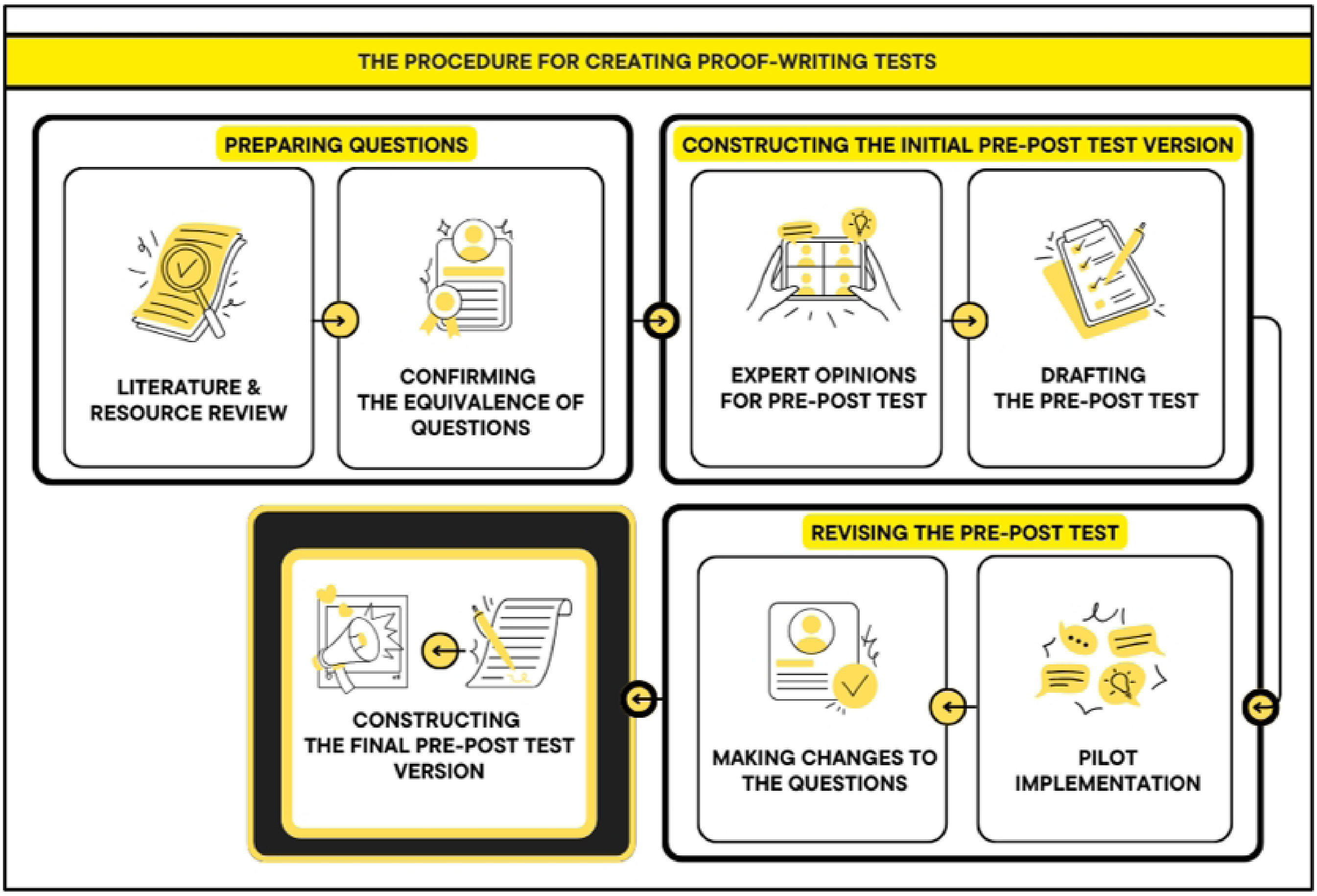
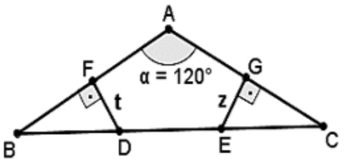
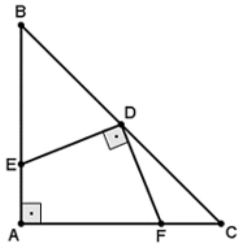


Figure 2: Procedure for creating proof-writing tests

Table 1 presents the detailed content of the questions in the PWPRE and PWPOST, as well as the prior knowledge required to demonstrate the mathematical relationships specified in the questions.

Test	Geometric Figure	Content	Prior Knowledge*
PWPRE		ABC is an isosceles triangle, $m(\hat{A}) = 120^0$. Given that the straight lines t and z are the perpendicular bisectors of [AB] and [AC] respectively, and that $t \cap [BC] = \{D\}$, $z \cap [BC] = \{E\}$, prove that |BD| = |DE| = |EC| with your justifications.	The definition of an isosceles triangle The properties concerning secondary elements.
PWPOST		The midpoint of the hypotenuse of the isosceles right triangle ABC is D. Points E and F are located on the sides [AB] and [AC], respectively, such that $m(\widehat{EDF}) = 90^0$. Prove that $A(ABC) = 2.A(AEDF)$ with your justifications.	The definition and properties of an isosceles triangle The angle-side-angle congruence theorem.

**The knowledge that pre-service teachers can be used for proof-writing the problems.*

Table 1: Explanations for some questions in the PWPRE and PWPOST

Process

The implementation occurred within a geometry course. Certain geometrical topics were covered during this course. Weekly proof-writing activities were conducted for the experimental group. These activities employed the ISMAT Model through collaborative group work. Each group was composed of three pre-service teachers. The control group's practices varied in that they did not incorporate proof-writing activities. Instead, direct mathematical statements were provided for proof-writing. However, classroom discussions focused on the proofs, with the instructor as the sole user of the dynamic software. Figure 3 illustrates the implementation process of a proof-writing activity. At the conclusion of the implementation process, a post-test was administered to assess the pre-service teachers' proof-writing skills. The treatment duration for each group spanned 14 weeks, encompassing both the proof-writing assessments and the introduction of the GeoGebra software. Subsequently, the data were analyzed comprehensively and interactively.

Table 2 serves as an illustrative example demonstrating the implementation process of a proof-writing activity accompanied by comprehensive explanations of the respective stages.

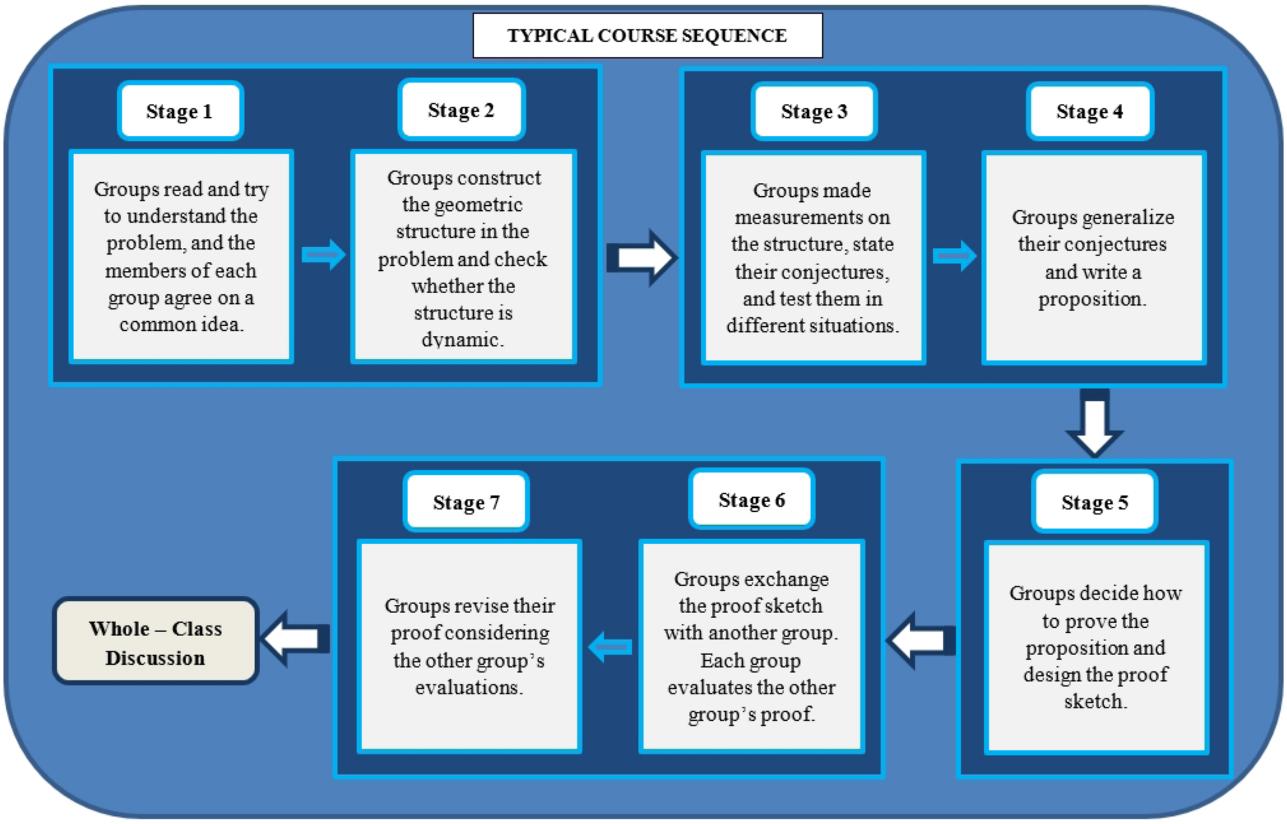
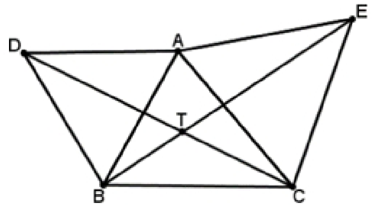
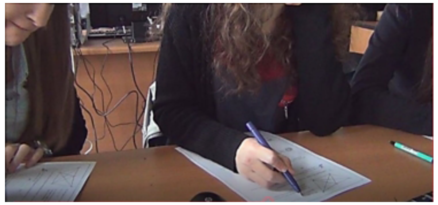
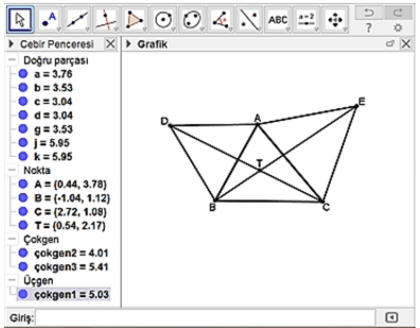
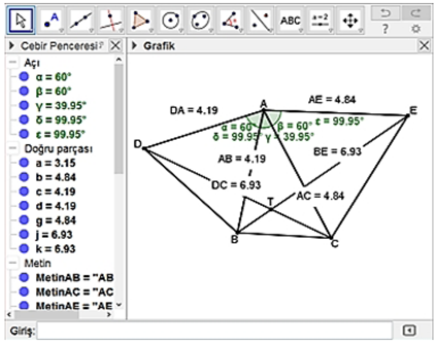
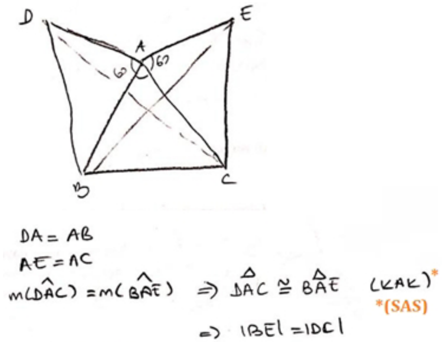
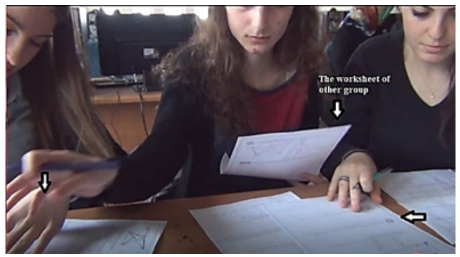


Figure 3: Typical course sequence based on the ISMAT model

<table>
<tr><th>Stage No</th><th>Description</th><th>Task</th><th>Reflection</th><th>Mathematical Behavior</th></tr>
<tr><td>1</td><td>Promote understanding of the problem by focusing on its essence, in other words, the givens.
Supporting the initial attempt to identify the existing mathematical relations.</td><td>
ABC is a triangle, BDA and AEC are equilateral triangles, $BE \cap CD = \{T\}$
According to the given information, determine whether there is a mathematical relationship between |BE| and |CD| by following the steps outlined below.</td><td></td><td>• Each group member reads about the problem.
• They try to understand the problem.
• Group members agree on a common idea.</td></tr>
<tr><td>2</td><td>Promote the construction of a structure by enabling one to think about the necessary geometric knowledge and drawing rules.</td><td>Considering the information provided, construct the geometric structure above.</td><td></td><td>• The group constructs the geometric structure in the problem by considering geometric knowledge and drawing rules.
• The group checks whether the structure is dynamic.</td></tr>
<tr><td>3</td><td>Promote working on the structure and conjecturing by enabling the making of numerous measurements on the geometric structure, searching for the mathematical relations, and testing the functionality of the conjectures for different situations.</td><td>a) Measure the lengths of the line segments BE and CD, and fill in the table with the corresponding measurement results. Note: The number of rows can be increased.<table><tr><th>|BE|</th><th>|CD|</th></tr><tr><td></td><td></td></tr><tr><td></td><td></td></tr><tr><td></td><td></td></tr></table>b) According to your measurements and investigations, what is the mathematical relation between |BE| and |CD|? Write this mathematical relation below.
Would your conjecture be valid if any regular polygons were substituted for equilateral triangles? Note: State which regular polygons you use.</td><td></td><td>• The group conducts several measurements on the dynamic structure.
• The group searches for relationships in the structure based on the measurements.
• Each group member makes several conjectures based on these relationships.
• The group discusses and evaluates the applicability of its conjectures in various circumstances.
• At the end of their investigation and discussions, the group members state a common conjecture.
• The group tries to determine the steps of proof based on experimental data.</td></tr>
</table>

Stage No	Description	Task	Reflection	Mathematical Behavior
4	Promote the postulation of the relationship by providing an opportunity to determine the hypothesis and draw conclusions.	Based on your investigations, state your hypothesis and conclusion, and write the mathematical proposition by making use of them. **Hypothesis:** **Conclusion:**		• The group generalizes their conjectures. • The group writes a proposition. • The group uses mathematical symbols and terms during the postulation.
5	Promote proving by enabling the determination of the definitions, axioms, or theorems for showing the correctness of the proposition, and designing the proof plan.	Design a proof sketch and state the steps you will follow, along with their justifications.		• The group decides on a method to prove the proposition. • The group determines the definitions, axioms, and theorems that will be used in the proof. • The group designs the proof sketch.
6	Promote the investigation of proof coherence by allowing the exchange of proof plans among groups and evaluating the proof of one group by another.	Exchange your proof plans with another group and evaluate the group's proof. **Note:** *Write your evaluations of the proof below*. **The names of the other group members:** **The evaluations of the proof:**		• The group exchanges proof plans with another group. • Each group evaluates the proof of the other group. • The group determines any deficiencies and errors.

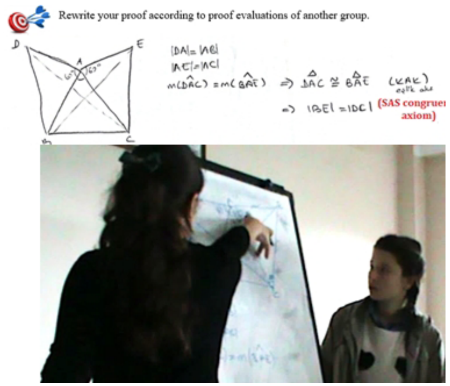
Stage No	Description	Task	Reflection	Mathematical Behavior
7	Promote formalization of the proof by providing an opportunity to revise deficiencies or errors in the proof plan.	Rewrite your proof according to the proof evaluations of another group.		• The group revises its proof in consideration of the other group's evaluations. • A group presents its proof to all groups. • A whole-class discussion is conducted. • The group finalizes its proof in accordance with the discussion that has taken place.

Table 2: Implementation process of a proof-writing activity based on the ISMAT Model

Data Analysis

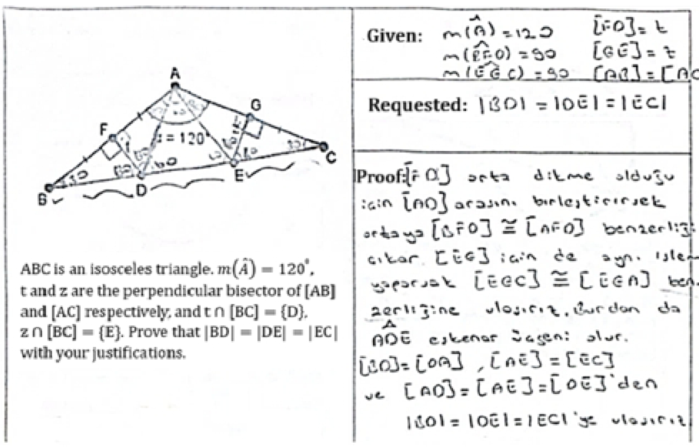
A modified version of Senk's (1983) 5-level scoring chart was utilized to assess data from proof-writing tests. This chart encompasses reasoning and mathematical language dimensions, allowing for integrated evaluations. While proof-writing entails various skills, including reasoning and justification, we posited that isolating these dimensions would yield more precise evaluations. Accordingly, *the Reasoning Process* was determined as one of the dimensions of the re-created scoring chart. Table 3 presents the categorical scoring chart formed to determine the pre-service teachers' proof-writing skills.

Reasoning Process (RP)	0-	S/he left it blank. S/he wrote the hypothesis and conclusion in detail. S/he came up with irrelevant statements or inferences that did not contribute to the proof.
	1-	S/he made at least one correct independent inference. S/he made his/her inference based on a case. However, while doing this, s/he was unable to provide sufficient justification. S/he made at least one inference starting from the conclusion.
	2-	S/he made successive inferences supporting one another. However, s/he failed to attain the result. S/he attained the result through successive inferences based on a special case. S/he attained the result, but s/he did not formally justify the steps s/he took in the process of reaching it, or just provided an incorrect justification.
	3-	S/he attained the result, but while some of the proof-writing steps were justified, others were not. S/he attained the result and justified a considerable part of the proof-writing steps. However, s/he made mistakes in some words and names of some theorems.
	4-	S/he attained the result by justifying each proof-writing step.

Table 3: Categorical scoring chart for evaluating proof-writing skill in terms of the reasoning process

The pre-service teachers' proofs were first examined using the categorical scoring chart to identify the effect of the learning environment, based on the ISMAT Model, on their proof-writing skills. Examinations were conducted to evaluate inter-researcher agreement on coding reliability proof related to the test. A random sample of 30% was selected from the papers of both groups for these examinations. Before the evaluations, the categorical scoring rubric was presented to the other researcher, accompanied by clarifications and examples of indicators. The examinations indicated an 83% concordance in coding between the researchers. Follow-up discussions addressed coding inconsistencies, leading to necessary adjustments. An example of data analysis for PWPRE and PWPOST, as shown in the chart below (see Table 4), is provided.

The scoring for each question on the PAPRE and PAPOST was recorded in an Excel file and transferred to Winsteps for analysis. The points given to the proofs of the problems in the tests through this program were converted into linear points through Rasch analysis. These linear points were the pre-service teachers' achievement points. Rasch analysis was used to overcome the problems likely to result from the fact that the differences between the categories on the scoring chart were not equal. Statistical analyses were made with the linear points obtained through the Rasch analysis. The Mann-Whitney U test was used to determine whether there was a statistically significant difference in reasoning achievement between the experimental and control groups before the experiment. This test was chosen due to the independence of groups and the non-normal distribution of achievement points. Covariance analysis was conducted to assess the significance of the difference in reasoning achievements between the experimental and control groups after the experiment, and to determine if this difference was due to the experimental conditions.

Test	Proof for PWT	Data Analysis
PWPRE		By stating the congruence of the triangle, it was written as $[BFD]\cong[AFD]$. A similar notation was preferred when writing the congruence of the EGC and ELC triangles. Instead of writing |AE| = |DE|, it was stated as [AE] = [DE]. For the other side of equality, it was also stated with this symbol. In the proof, there are only deficiencies in the mathematical symbols. Therefore, this proof belongs to RP3.

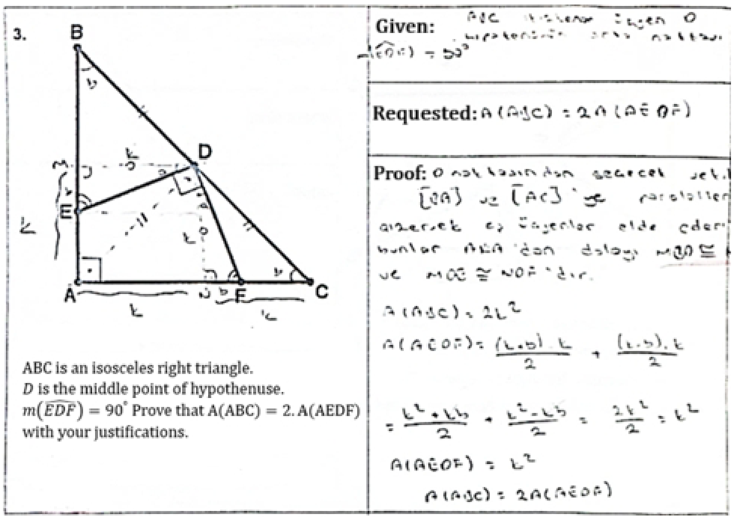
Test	Proof for PWT	Data Analysis
PWPOST		In the proof, the chain of inference is written appropriately. All the justifications between inferences were stated. Besides, when writing proof steps, mathematical language is taken into consideration. Therefore, this proof is in RP4.

Table 4: Example of data analysis for PWPRE and PWPOST

RESULTS

Results Concerning the Pre-service Teachers' Proof-Writing Skills before the Experiment

The pre-service teachers' proofs in the pre-test were evaluated, and then each of their proof-writing skills was determined. Table 5 presents the frequency and percentage distribution obtained from evaluating the proofs in PWPRE.

As Table 5 indicates, 39% of the experimental group proofs and 51.47% of the control group proofs were categorized as RP0 before the experiment, denoting a predominance of proof in this category among pre-service teachers. A significant number of these proofs merely restated the problem without generating inferences. Instances also occurred where pre-service teachers either omitted responses or included irrelevant statements that did not contribute to the proofs. Furthermore, 31% of the experimental and 28.8% of the control group proofs fell into RP1, which succeeded RP0. The majority of RP1 proofs in both groups (21.6% experimental, 19.35% control) included at least one correct independent inference, indicating a transition from RP0 to RP1, with a focus on hypothesis and conclusion details. Some instances contained inferences based on cases without sufficient justification, although at least one inference from the conclusion was made, albeit less frequently than correct independent inferences. Inferences from the conclusion were limited in occurrence across all reasoning process categories in both groups. Figure 4 illustrates a proof that corresponds to RP1, which was the most prevalent case in both groups before the experiment, following the identification of details on the hypothesis and conclusion.

Categories	Experimental Group		Control Group	
	f	%	*f*	%
RP0	150	39.00	173	51.47
RP1	119	31.00	97	28.88
RP2	70	18.30	45	13.39
RP3	27	7.00	16	4.77
RP4	18	4.70	5	1.49

Table 5: Frequency and Percentage Distribution Before the Experiment

The pre-service teacher illustrated the measure of arc AB because angle ACB is inscribed in it. However, she incorrectly inferred that line segment TC was a tangent and that the bisector of angle BTA passed through the circle's center, despite only one tangent being drawn from point T. Consequently, she believed that ray TR bisected arcs AB and AC equally, leading her to assume she had established the specified mathematical relationship. Thus, she presented a proof containing both correct and incorrect inferences, including at least one valid conclusion. The interview revealed her familiarity with the mathematical statements employed in her proof and the requisite actions, yet she struggled to articulate them effectively.

Some proofs by pre-service teachers fell into RP2. The control group produced fewer proofs in this category than the experimental group. While they made necessary inferences, they occasionally lacked formal justification or provided incorrect justifications. A similar pattern was observed in cases involving inferences from special cases. Additionally, in RP2 proofs, some pre-service teachers failed to make mutually supportive inferences, though this was less common across both groups compared to other RP2 cases. Before the experiment, pre-service teachers produced proofs in RP2 mainly when they could draw a conclusion. Therefore, when able to make the necessary inferences, they provided proofs that contained reasoning gaps. Figure 5 illustrates one proof corresponding to RP2.

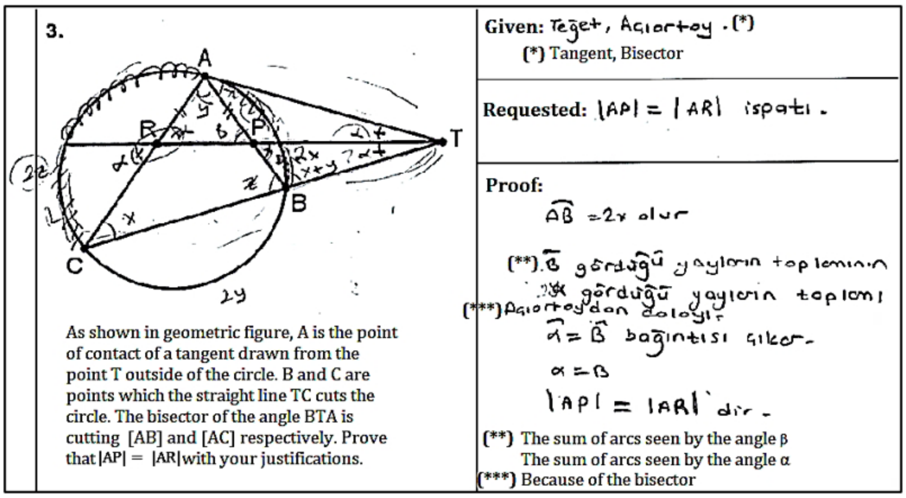


Figure 4: Example of a proof corresponding to RP1

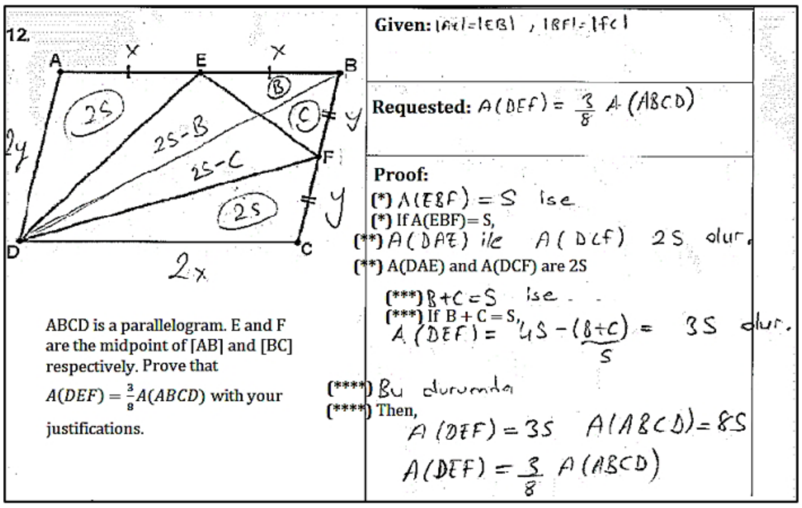


Figure 5: Example of a proof corresponding to RP2

As illustrated in Figure 5, the pre-service teacher defined the triangle EBF's area as S and deduced the equality of areas for triangles DAE and DEB; she calculated triangle DEF's area as 4S - (B + C) based on her notation; she concluded the area of triangle DEF is 3S; and the area of parallelogram ABCD is 8S. Despite making all the necessary inferences for the mathematical proof, she failed to provide justifications for these deductions. The interview revealed her awareness of her reasoning processes; she attributed her lack of justification to her prior experience of solving problems rapidly in mathematics courses.

The experimental group of pre-service teachers demonstrated a higher frequency of proofs in RP3 (7%) than the control group (4.77%). Justifications for selected proof-writing steps were more common than complete justifications for all steps. Instances of substantial step justifications with errors in terminology occurred, though these were less frequent. In RP4, where all inferences required for proof-writing were justified, the experimental group had a rate of 4.7%, compared to 1.49% in the control group. Nevertheless, the overall rate for this category was lower than that of other categories. Higher reasoning process categories (RP2, RP3, RP4) were observed less frequently in both groups than lower-level categories. This suggests that pre-service teachers struggled to identify all necessary proof-writing steps. It also reflects a deficiency in skills for justifying proof-writing steps or a perceived lack of necessity for such justifications. The infrequency of complete inferences and justifications indicates inadequate preparation for proof-writing before the experiment.

The Mann-Whitney U test, a non-parametric measure, was applied to the pre-test data to determine whether there was a statistically significant difference between the experimental and control groups in terms of reasoning achievement before the experiment. Table 6 presents the results of this test.

	Group	*N*	Mean Rank	Rank Sum	*U*	*p*
Pre-Test	Experimental	32	38.03	1217	207	0.000
	Control	28	21.89	613		

Table 6: Result of the Mann-Whitney U Test

Table 6 reveals that, prior to the experiment, there was a significant difference between the experimental group and the control group in terms of achievement in reasoning, favoring the former ($U = 207$, $p < 0.05$).

Results Concerning the Pre-service Teachers' Proof-Writing Skills After the Experiment

The pre-service teachers' proofs in the post-test were evaluated, and then each of their proof-writing skills was determined. Table 7 presents the frequency and percentage distribution obtained from evaluating the proofs in the PWPOST.

After the experiment, the proportions in RP0 were 14.06% in the experimental group and 43.45% in the control group. This suggests that the control group predominantly provided proofs in RP0. Conversely, the experimental group exhibited a significant reduction in RP0 proofs relative to the baseline, highlighting a notable disparity between the groups. The proofs in RP1 were 31.78% in the experimental group and 36.31% in the control group. Despite being less frequent in the experimental group, RP1 had the highest proportion among its categories. Most RP1 proofs in both groups involved "*making at least one correct independent inference*."

The RP2 category was more prevalent in the experimental group (27.08%) compared to the control group (12.2%). Despite its higher occurrence in the experimental group, the case of "*failing to attain the result by making inferences that support one another*" was common in both groups. This indicates that, post-experiment, pre-service teachers increasingly focused on the interconnections of inferences during proof-writing. Figure 6 illustrates a proof example related to RP2.

Categories	Experimental Group		Control Group	
	f	%	f	%
RP0	54	14.06	146	43.45
RP1	122	31.78	122	36.31
RP2	104	27.08	41	12.2
RP3	65	16.92	22	6.55
RP4	39	10.16	5	1.49

Table 7: Frequency and percentage distribution after the experiment

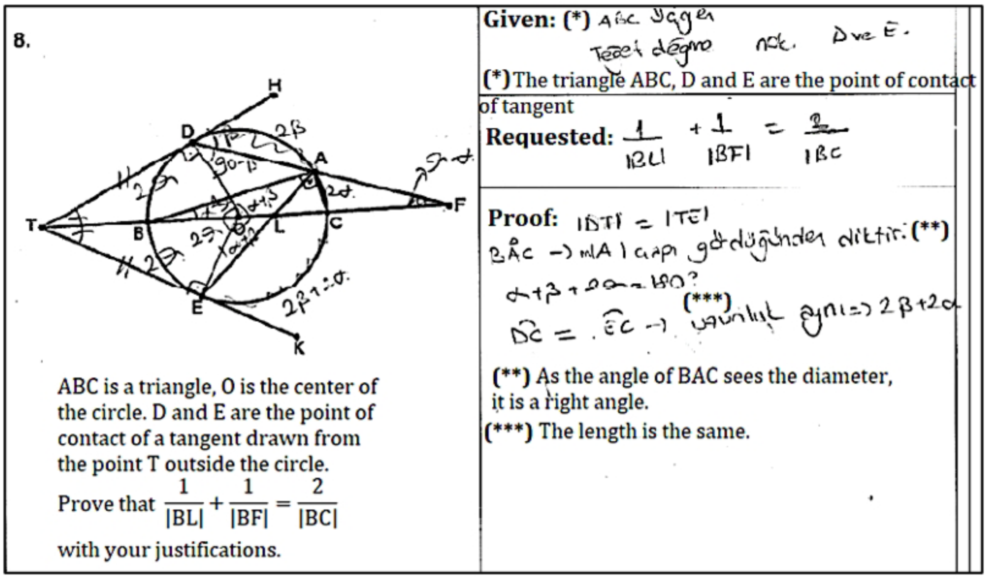


Figure 6: Example of a proof corresponding to RP2

As illustrated in Figure 6, the pre-service teacher inferred |DT| = |TE| from a tangent at point T. She established angles TDO and TEO as 90 degrees, based on the perpendicularity of the radius to the tangent. She deduced that angles DTO and ETO are equal because the line segment TF intersects the center of the circle. Consequently, she claimed that arcs DB and BE, as well as arcs DC and EC, were equal in measure. Additionally, she posited that angle BAC measures 90 degrees, justifying her assertion by its opposition to the diameter of the circle. Thus, she constructed a series of interconnected inferences. Nevertheless, her proof remained incomplete due to her omission of necessary concluding inferences.

The RP3 category proofs were more frequent in the experimental group (16.92%) than the control group (6.55%). Control group students exhibited a significantly lower percentage of RP3 proofs relative to their experimental counterparts. In both cohorts, the predominant proofs involved justifying certain steps in the proving process, with greater frequency in the experimental group. Limited instances of proofs that justified substantial steps but included errors in terminology were exclusive to the experimental group. This suggests that post-experiment, pre-service teachers, particularly in the experimental group, recognized the necessity for justifying their inferences related to proofs. Figure 7 illustrates an example of a proof relevant to RP3.

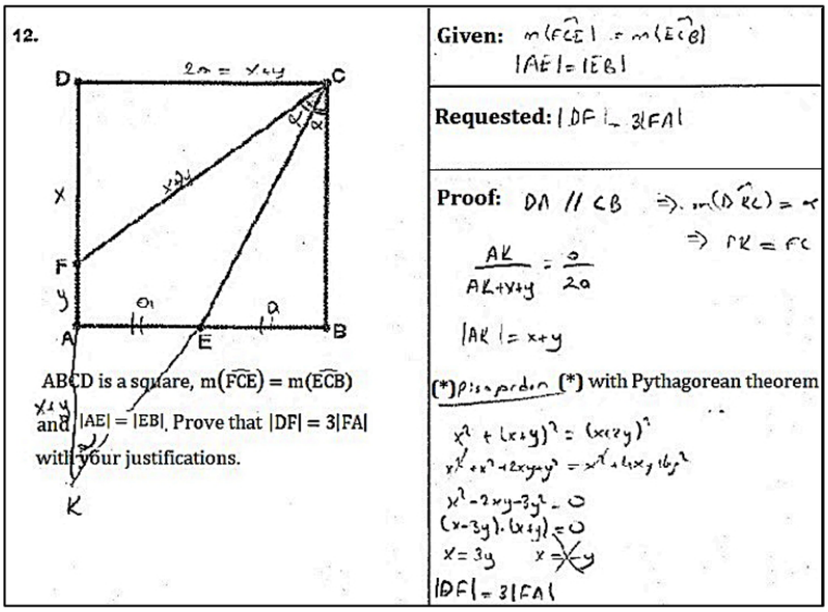


Figure 7: Example of a proof corresponding to RP3

As illustrated in Figure 7, the pre-service teacher articulated that $m\left(\widehat{DKC}\right)=\alpha$ by asserting the parallelism of line segments DA and CB, attributing this to quadrilateral ABCD being a square. He failed to justify the operation "$\dfrac{AK}{AK+x+y}=\dfrac{a}{2a}$", which he executed based on his personal interpretation of letters and supplementary drawings. He indicated that the operation he initiated as "$x^2+(x+y)^2=(x+2y)^2$" was predicated on the letters assigned to the side lengths in accordance with the Pythagorean Theorem. Thus, while he provided rationales for certain inferences made during the proof, he omitted justifications for others.

The experimental group showed a proof rate of 10.16% for RP4, while the control group exhibited a rate of 1.49%. Nevertheless, both groups had lower rates in this category compared to others. Additionally, the control group showed no change in RP4 proof rates pre- and post-experiment. In contrast, the experimental group experienced an increase in RP4 proof rates. An illustration of an RP4 category proof is presented in Figure 8.

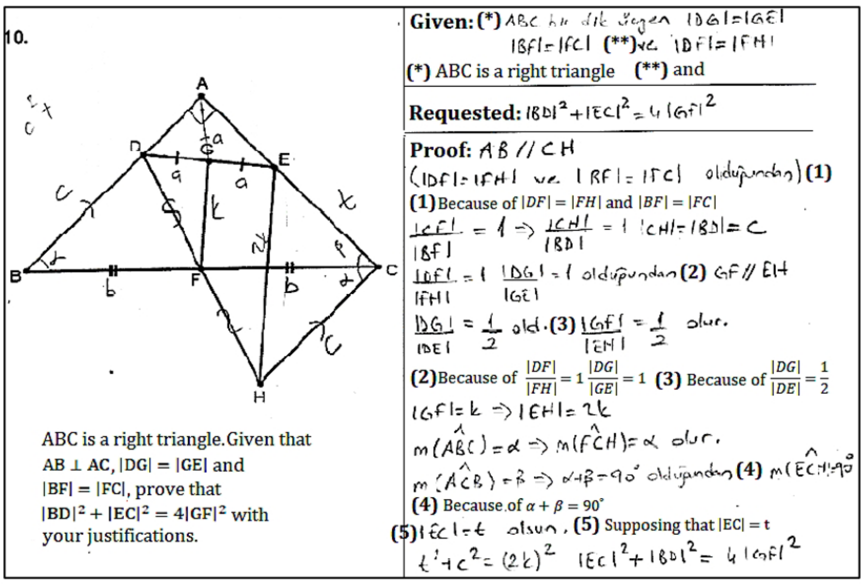


Figure 8: Example of a proof corresponding to RP4

As illustrated in Figure 8, the pre-service teacher asserted that the ratio of the triangles DFB and HFC was equivalent, leading to the conclusion that line segments AB and CH are parallel. She claimed that the lengths of segments BD and CH were identical and provided sound reasoning for this conclusion. Her assertion of the parallelism of sides GF and EH, based on the side length ratio, constituted a valid step in the proof. She established angle measures accordingly and deduced that angle ECH is 90 degrees, offering a well-founded justification for this inference. Her utilization of the Pythagorean Theorem, predicated on this angle measurement, represented a legitimate and conclusive step in the proof. Consequently, she delivered a comprehensive proof in RP4 by articulating each necessary inference and thoroughly substantiating each assertion.

According to the categories of the reasoning process, the comparison of the proof rates for the experimental and control groups before and after the experiment is shown in Figure 9.

As Figure 9 demonstrates, the experimental group primarily produced proofs in all reasoning categories except RP0 prior to the experiment. Post-experiment, the control group favored proofs in RP0 and RP1, while the experimental group dominated in RP2, RP3, and RP4. The control group showed a higher prevalence of non-proof statements compared to the experimental group. In contrast, the experimental group presented a larger number of statements with proof quality, despite some shortcomings in mathematical language or justification.

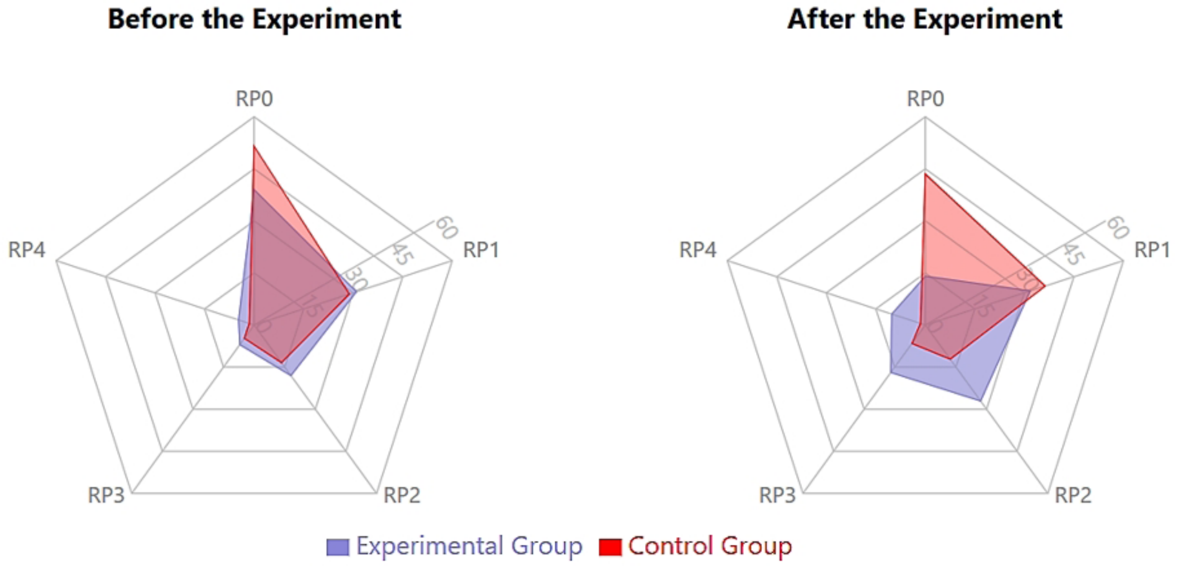


Figure 9: Radar graph for comparison of the groups' proof rates before and after the experiment

An analysis of covariance (ANCOVA) was carried out using the pre-test scores as the "covariate" to determine whether there was a significant difference between the groups' post-test scores concerning their achievement in reasoning, and if so, whether such a difference really resulted from the experimental conditions. Table 8 presents the descriptive statistics for the mean post-test scores, along with the reasoning behind the calculations, as well as the adjusted mean post-test scores. Table 9 presents the results of the ANCOVA, demonstrating whether the difference between the adjusted mean post-test scores of the groups is statistically significant.

Group	*n*	Post-Test Score		Adjusted Post-Test Score	
		$\bar{X}$	SD	$\bar{X}_a$	*SH*
Experimental Group	32	0.35	0.47	-0.129	0.152
Control Group	28	-0.84	1.35	-0.652	0.163
Total	60	-0.37	1.07		

$\bar{X}_a$: Adjusted Mean Post-Test Score

Table 9: ANCOVA results concerning the post-test scores concerning achievement in reasoning in the proving process

Source of Variance	Sum of Squares	Sd	Mean Square	*F*	Level of Significance	Effect Size (eta-square)
Pre-test	16.277	1	16.277	23.144	0.000	0.289
Method	3.681	1	3.681	5.234	0.026	0.084
Error	40.089	57	0.677			
Total	76.111	60				

Table 8: Descriptive statistics of the post-test scores concerning the experimental and control group students' achievement in reasoning in the proving process

According to the results of the ANCOVA, as shown in Table 9, there was a statistically significant difference between the post-test scores of the experimental group and those of the control group when the two groups' pre-test scores were controlled ($F_{(1, 57)} = 5.234$, $p < 0.05$). In other words, the improvement in the pre-service teachers' achievement in reasoning was associated with the activities carried out in the learning environment based on the ISMAT Model. Accordingly, the lessons on proof conducted in the learning environment designed for the experimental group contributed to the improvement in the pre-service teachers' achievement in reasoning.

DISCUSSION AND CONCLUSION

Progress in pre-service teachers' reasoning was observed within the ISMAT Model. The experiment revealed a decline in proofs for the lower reasoning categories (RP0, RP1), while proofs for the higher reasoning categories (RP2, RP3, RP4) increased. The experimental group experienced a decrease from 39% to 14.06% in the RP0 category, representing a reduction of more than 50%. Conversely, the control group experienced a minor decrease from 51.47% to 43.45% in the same category. The experimental group exhibited significant changes compared to the control group. This may be attributed to the researcher's emphasis on distinguishing between given conditions and required proofs. Consequently, pre-service teachers faced fewer challenges in initiating mathematical proofs. The rate of cases corresponding to RP0 decreased from 39% to 14.06%, indicating an increase in proof attempts. The success in initiating proofs likely bolstered their confidence and reduced their inclination to leave questions unanswered. It can be posited that heightened motivation and positive emotions facilitated deeper study and enhanced learning efforts (Heinze & Reiss, 2009). Although some proofs remained incomplete, increased self-confidence fostered a reasoning mindset that initiated the process of proving. Thus, post-experiment, pre-service teachers employed various reasoning methods to initiate proofs. Moore (1994) suggested that a lack of conceptual understanding can hinder the initiation and execution of proof. In alignment with this, the current study indicates that the pre-service teachers' conceptual understanding improved through the use of the ISMAT Model.

The proportion of proofs in RP2 increased from 18.3% to 27.08% post-experiment. This indicates that the experimental group improved in identifying all the necessary steps required to complete the proof. Consequently, a transformation occurred in the integration of supporting inferences into a cohesive presentation. This shift likely enhanced the pre-service teachers' reasoning skills, fostering a comprehensive perspective. This finding aligns with previous research indicating that reasoning improvement activities positively influence learners who initially exhibited inadequate proof explanations (Driscoll, 1987; Lee, 1999; Mata-Pereira & da Ponte, 2017; Moore, 1994; Schoenfeld, 1985).

The occurrence rate of proofs in RP3 increased from 7% to 16.92% post-experiment. This denotes a more than two-fold enhancement in proof occurrence. It suggests that pre-service teachers recognized the significance of justifying their inferences and integrating various inferences cohesively. Additionally, it indicates a tendency to scrutinize the basis of their expressed inferences. Pre-service teachers exhibited increased awareness of mathematical expression utilization. Such advancements likely stemmed from discussions surrounding the mathematical expressions and justifications presented during the proving of relationships. These improvements may have been promoted by discussions in the experimental group regarding the suitability of expression, grounds for inferences, and the relevance of justification. Lee (1999) articulated that prompting students to elucidate their reasoning enhances their proof-writing skills. Nonetheless, the proof count in RP3 fell short of expectations, possibly due to some group members merely observing and recording rather than actively engaging. Students who did not critically engage with the proof steps may not have achieved the same advancements in individual proof-writing assessments.

The occurrence rate of proofs in RP4 increased from 4.7% to 10.16%, indicating a significant rise. This suggests that pre-service teachers enhanced their awareness of the necessary inferences for proofs and justifications. Their improved expression of inferences and justifications reflects a solid grasp of reasoning processes. This progress likely stemmed from the experimental learning environment, which facilitated discussions on the correctness and relevance of inferences and justifications. However, these advancements were insufficient, potentially due to a lack of focus on improving spatial skills, such as drawing. Consequently, the anticipated increase in proofs may not have materialized, as additional drawing questions would require deeper, multi-dimensional reasoning. Additionally, some pre-service teachers' increased efforts in group work to identify and justify proof-writing steps may have influenced these outcomes.

The frequency of higher reasoning proofs (RP2, RP3, RP4) among pre-service teachers increased post-experiment. This indicates that the ISMAT Model learning environment enhanced their reasoning in the proving process. Control group proof data from before and after the experiment further corroborates this finding. Notably, proofs in RP0 were most prevalent after the experiment, followed by RP1. While a minor rise in RP3 proofs was observed, RP2 experienced a decline, and RP4 remained stable. This suggests that proof teaching for the control group had minimal impact on their reasoning. Consequently, the experimental group's proof teaching effectively improved their reasoning skills. Previous research has similarly highlighted that various educational strategies fostered student reasoning development (Erdem, 2015; Francisco & Maher, 2005; Generazzo, 2011; Hiebert & Grouws, 2007; Hsu, 2010; Lee, 1999; Martin & McCrone, 2009; Pulley, 2010; Reiss, Hellmich & Reiss, 2002).

Proof evaluation activities enhance students' reasoning, aligning with Pulley's (2010) findings that such activities dispel misconceptions and strengthen understanding of mathematical proofs. These activities are pivotal for pre-service teachers, facilitating the analysis of peer proofs, comparison with their own inferences, and fostering awareness of diverse proof-writing techniques.

We assert that the pre-service teachers' presentations may have transformed their reasoning through exposure to diverse proof-writing techniques. This assertion is corroborated by various studies (e.g., Generazzo, 2011; Pulley, 2010; Weber et al., 2008), which indicate the beneficial impacts of class discussions on the learning process. Generazzo (2011) posits that designated time for class discussions can enhance both reasoning and proof-writing skills, fostering positive shifts in students' perspectives on proof-writing. In our study, interactive group work, peer sharing of insights, and the opportunity to recognize and rectify mistakes contributed to advancements in reasoning during the proving process. Furthermore, numerous researchers emphasize the significance of group work in proof teaching, noting that interactive environments facilitate reasoning enhancement (Generazzo, 2011; Haralambos, 2000; Lee, 1999; Moreno, 2003; Pulley, 2010; Tinto, 1990). Yankelewitz, Mueller and Maher (2010) similarly highlight that settings that promote peer interaction and the expression of mathematical ideas are optimal for developing mathematical reasoning. In this context, drawing from Vygotsky's (1978) perspective, it can be concluded that reasoning improvement occurs in socially interactive environments, as individuals are influenced by the reasoning of their peers (Maher & Davis, 1995).

The structural alignment of the ISMAT Model with the methodological procedures employed by professional mathematicians provides pre-service mathematics teachers with a systematic framework for developing proofs, which contributes significantly to both pedagogical efficiency and professional accountability. Results supported by Buchbinder and McCrone (2023) demonstrate that structured module-based approaches enhance pre-service teachers' content and pedagogical knowledge regarding the role of examples and quantifiers in proofs. The model optimizes time-to-competency ratios while enhancing the quality of evidence-based reasoning relative to initial knowledge levels, supported by Al-Sa'ad and Alzoebi (2024), who confirmed that systematic training programs based on NCTM standards produce statistically significant gains in teachers' pedagogical knowledge across multiple dimensions. Furthermore, ISMAT's systematic approach cultivates metacognitive awareness among pre-service teachers, aligning with the pedagogical-metacognition model proposed by Kohen and Kramarski (2018), and strengthening their ability to identify and correct errors within their own learning processes. Evidence from Erdoğan and Kalkan (2024) reveals that metacognitive awareness explains 38% of the variance in critical thinking scores, supporting a transformative shift from passive knowledge acquisition to active knowledge construction. The socio-constructivist dimension, supported by Generazzo (2011) and Pulley (2010) and enhanced by collaborative evidence-based reasoning processes emphasized by Csanádi et al. (2021), demonstrates that the model extends beyond individual cognitive development to encompass collaborative mathematical discourse and peer-mediated learning experiences, positioning the ISMAT Model as a theoretically grounded, empirically supported, and pedagogically innovative approach in mathematics teacher education.

Several limitations must be recognized when analyzing these results. Primarily, the research was conducted within a single institution, which may limit the applicability of the findings to alternative educational settings characterized by diverse student demographics, institutional cultures, or resource availability. Secondly, the hierarchical organization of the data, with students organized within classrooms, may have introduced interdependencies that could potentially influence the statistical interpretations, as conventional analyses presuppose the independence of observations. Thirdly, the evaluation was confined to assessments conducted immediately following instruction without any longitudinal follow-up, thereby rendering uncertain whether the noted enhancements in proof-writing skills are sustained over time or merely indicative of transient improvements. Lastly, the experimental group's exposure to innovative teaching methods and dynamic geometry software may have resulted in enhanced performance due to Hawthorne or novelty effects rather than the inherent effectiveness of the ISMAT Model itself. The increased attention and motivation from participating in a novel educational approach could have confounded the true impact of the intervention. Future studies should address these limitations through multi-institutional studies, appropriate statistical modeling for nested data, longitudinal follow-up assessments, and careful control for attention effects to provide more robust evidence of the ISMAT Model's effectiveness in developing proof-writing skills.

Based on the results of this research, it is recommended that proof teaching be grounded in real-life mathematical activities. Moreover, instructional models should facilitate student involvement in the proving process. Additionally, since proof teaching is crucial at all educational levels, the ISMAT Model could be adapted accordingly. Consequently, further research is warranted to evaluate the effectiveness of the ISMAT Model across various educational stages.

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Full research paper

THE POSITIVE AND NEGATIVE IMPACT OF ONLINE SOCIAL TIES ON PA BEHAVIOUR: A QUALITATIVE ANALYSIS IN CHINESE ADOLESCENTS

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ABSTRACT

The continuing downward trend in low physical activity levels among Chinese adolescents increases the risk of obesity and negative mood and is associated with poorer mental and physical health. Integrating physical activity within one's social relationships influences physical activity behaviour. Although strong social ties, such as family members, peers, and educators, are influential on adolescents' physical activity, it is also acknowledged that adolescents may build social ties through social media, potentially impacting their physical activity behavior. The current study aimed to gain a deeper understanding of Chinese adolescents' social ties in social media and how this might impact their physical activity behaviour. For this purpose, a qualitative study design was used. We conducted 13 qualitative focus groups that sampled 74 Chinese adolescents. Social support and perceived barriers were identified. Consistent with social ties-related theory (e.g., social integration theory, social engagement theory, etc.), our findings emphasize the need for incorporating the positive influences of strong social ties of peers and parents, as well as weak and peripheral ties of fitness influencers and people from the online PA community with similar PA interests, into the design of social media interventions.

KEYWORDS

Educational process, future teachers, information and communication competence, information and communication technologies, laboratory work, natural sciences

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Highlights

- *Both offline (parents, peers) and online ties (influencers, communities) significantly shape Chinese adolescents' physical activity.*
- *Positive effects include role modelling, virtual companionship, and competition, which boost exercise motivation.*
- *Negative effects arise from misinformation, online distraction, body image pressure, and gender stereotypes.*
- *Diverse strong and weak ties can provide scalable, low-cost PA support, but safeguards are needed against harmful influences.*

INTRODUCTION

Studies have demonstrated that the majority of Chinese school-aged adolescents have inadequate levels of physical activity (PA) and physical fitness (Chen et al., 2017). There is a general downward trend in PA (Ao et al., 2019) and physical fitness (Dong et al., 2019). A recent study found that only 5.12% of Chinese children and adolescents meet the 24-hour movement guidelines (Chen et al., 2021), while 85.8% of school students engage in leisure sedentary behaviors for longer than 2 hours per day (Song et al., 2019). However, sufficient physical activity (PA) contributes to better overall physical and mental health, physical fitness, and a lower level of obesity in adolescents (Granger et al., 2017). Therefore, it is necessary to increase Chinese adolescents' daily PA.

It is important to know the influencing factors for adolescents' PA behaviour. Adolescent PA is often influenced by socialization and social networking. The significance of social ties' influence on PA has been discussed by numerous scholars. The strength of an interpersonal tie is defined as "a (probably linear) combination of the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie" (Granovetter, 1973, p. 1361). Among other social ties, peers, parents, and educators proved to be important influencing factors in adolescents' PA behaviour. Family members and close friends could be referred to as "strong ties", as they are people "one knows well" and usually have a strong emotional bond in the relationship (Gilbert, 2012). Correspondingly, casual acquaintances are referred to as "weak ties" because there is only a weak emotional bond in these relationships. However, it is unlikely that today's adolescents' PA is only influenced by their strong social ties. Nowadays, adolescents' diversity of social ties should also include online connections that have become indispensable for their social relationships. Social media, in particular, has been identified as a powerful tool for reaching, accessing, influencing, and changing PA and diet-related behaviors (Goodyear et al., 2018). Specifically, not only can social media connect adolescents with their offline strong ties, but it can also be an important way to expand adolescent weak ties (i.e., individuals outside the network of close social ties), for instance, to get to know new people online. The weak ties could even include para-social relationships, such as social media fitness influencers. These types of influencers specialize in sharing fitness and food-related content, often associated with objectifying pictures of males and females (Durau et al., 2022; Tiggemann and Zaccardo, 2018). Although para-social relationships usually refer to interactions with a media personality that are perceived to be intimate and authentic (Horton and Wohl, 1956). However, this relationship is also viewed by the literature as gratification for the viewer (Rubin and McHugh, 1987; Horton and Wohl, 1956), which suggests that the one-sidedness of relationships with fitness influencers could be adolescents' weak ties in the online world.

Furthermore, social integration and social engagement theories indicate that diverse social ties show benefits by connecting individuals to resources and activities (Thomas, 2012). Interacting with diverse people entails engaging in diverse behaviours (Litwin and Stoeckel, 2016). In line with these theories, it is expected that peripheral or weak ties expose individuals to novel behaviors and activities (e.g., leisure, volunteer work) that they do not experience with strong ties (Fingerman, 2009), especially those formed through online social networking. Interacting with online peripheral ties and online weak ties could change behavioural patterns. It may have various influences on adolescents' PA, including some influences that adolescents may not experience from merely offline strong social ties. Therefore, it is essential to consider online and social relations.

Social support and stress are key mechanisms through which social ties affect health behaviour (Umberson et al., 2010). While social support includes instrumental (e.g., help with tasks), informational (e.g., advice), and emotional (e.g., a sense that one is loved, cared for, and listened to) support, it has long been highlighted in research on the health benefits of social ties (Taylor and Repetti, 1997). However, social ties also have their negative sides. Stress is a central dimension of the negative side of social ties (Cohen et al., 2004). Stress refers to life disruptions and chronic strains (e.g., ongoing conflict in relationships) that challenge individuals' coping capacities (Pearlin et al., 2005). Importantly, numerous studies have documented that stress, in turn, contributes to poor health habits in adolescence (Kassel et al., 2003). However, these mechanisms are less explored for online social ties' influence on adolescents' PA. A lack of research was especially identified regarding the potential benefits or possible adverse effects of a more diverse online network that includes peripheral or weak social ties on Chinese adolescents' PA behaviour.

Last but not least, existing evidence on adolescents' PA is dominated by Western samples and strong ties (parents/close peers), while studies in Asian contexts rarely disentangle the roles of weak online ties such as influencers or open communities (Engel et al., 2024; Jia et al., 2025; Zhang et al., 2024; Wang et al., 2024). Therefore, to gain a deeper understanding of Chinese adolescents' social ties in social media and how this might impact their PA behaviour positively or negatively, our study explicitly addresses this gap by aiming to map which online agents—across strong and weak ties—shape Chinese adolescents' PA and through which mechanisms. Through exploring this gap, we could also inspire how online social ties may provide lower-cost, scalable support for PA while requiring safeguards against harmful social influences, aiming to improve educational responsibility and efficiency.

METHODS

Participants

We chose a qualitative focus group approach to explore factors that influence opinions, behaviour, or motivation (Krueger, 2014). Eligibility criteria for the group discussion required adolescents to be between the ages of 10 and 19 years (WHO defines 'Adolescents' as individuals in the 10-19 years age group) and living in urban areas, as it is also important to consider the urban-rural disparities in China, including variations in gender and moral norms that can impact access and usage of media technology (McDonald, 2016). Based on these considerations, the first author contacted a high school and a university in Huhhot (a northern urban city in China, Inner Mongolia. There are several reasons for selecting this city. Considering the long period and daily commuting to classrooms for group discussions and research costs, it is more feasible to conduct the research in the city where the first author resides.

Furthermore, it is more likely to obtain permission from school leaders to conduct research with adolescent students, as the first author is more familiar with the teachers from these two schools. To ensure diversity of opinion, we recruited 46 participants between the ages of 14 and 16 as younger adolescents and 28 participants between the ages of 17 and 19 as older adolescents. We also ensured that 37 male students and 37 female students were equally represented.

Procedure

Over four months, starting in March 2021, 14 focus group meetings were conducted with 74 Chinese adolescents.

Each focus group consisted of five to seven participants. Concerning saturation and the stopping rule, data collection continued until codebook stabilization, as no new first-order codes or substantively distinct subthemes emerged over two consecutive focus groups. The researcher therefore decided to stop after 14 groups had been formed. Before each focus group, an explanation of the study's aim was provided, and informed consent (in which participants' anonymity and confidentiality were assured) was signed by each participant and one of their guardians. All participants agreed to participate in the study. Afterwards, all participants were asked to complete a short demographic questionnaire. The average length of each focus group interview was around 30 minutes. The first author independently conducted the coding. To enhance trustworthiness, she engaged in repeated reading and iterative refinement of the codebook until stabilization. Credibility was strengthened through member checks with participants, and dependability was supported by peer-debriefing sessions where preliminary themes were discussed with senior colleagues. NVivo 12 was used to assist in data management and organization.

Interview Guide

Based on the aim of this research, a semi-structured interview guide consisting of seven open-ended questions was designed to ask about participants' experiences with the influences of online social ties on their PA behaviour. The first question aimed to identify general perceived social influences on adolescents' PA behaviour through social media. The following questions were structured in the two overarching themes of social support through social media (e.g, What content or information on social media platforms makes you feel more confident participating in PA?) and perceived stress through social media (e.g, In your opinion, what are the negative influences of using social media on your PA participation?)

Data Analyses

All interviews transcribed verbatim, and data were analyzed following a thematic content analysis in the following steps. Data analysis was undertaken using a computer, but not with a specific computer package. The first author coded the interviews, and the other authors provided feedback on the first author's analysis. We used standard thematic analysis to analyze the transcripts. Thematic analysis is the systematic examination of text by identifying and grouping themes and coding, classifying, and developing categories (Whitley and Crawford, 2005). After creating broad categories based on research objectives and interview notes (categories related to social support and stressful experiences), the primary author coded the transcripts. At this exploratory phase of data coding, initial codes like "informational support", "emotional support", or "a combination of informational support and emotional support" were identified. However, we merged codes once we identified significant conceptual overlap between codes. For instance, we identified substantial patterns of support, including informational and emotional social support through role modeling. In this case, we combined the codes and concepts into sub-themes, such as "informational support and emotional support from role models." And then placed them under the highest category, namely the theme of "social support." As a last step, when writing up the results, quotes were translated into the English language and cross-checked for the accuracy of the translation.

Quality and Rigor

Firstly, member checks, also referred to as 'respondent or participant validation,' are commonly employed as a means of maintaining validity in qualitative research (Creswell and Miller, 2000). This was addressed in the present study by inviting two students who participated in focus group discussions to review the consistency of the themes with their own descriptions and those of their peers' general experiences. Both indicated that the themes identified comply with their living experiences.

Secondly, although the first author completed the coding process independently, all authors participated in and contributed to the identification of the final themes after the first author had completed the initial draft of the identified themes. The final themes presented in this research have undergone multiple rounds of discussion and modification to ensure multiple truths, perspectives, and results in the research process, therefore enhancing the rigour of this research.

RESULTS

Two themes, namely social support and perceived barriers, and five subthemes were generated through the analysis. Within the theme of social support, participants explained how they received useful PA-related information and exercise motivation from both individuals they are related to in offline environments and those they are only connected to through social media. Another aspect, explained in the subtheme 'emotional support and companionship', was the use of competition, virtual companionship, and tracking tools on social media, which motivated them to exercise. Perceived barriers included the distraction of peers through social media, the negative impact of fitness influencers, and the negative influences of online people. See Table 1 for a brief illustration of themes and sub-themes.

Theme	Subtheme	Direction	Tie type	Operational definition	Representative quote	Implication
Positive	Role modelling	+	Strong & weak ties	Observing parents, peers, influencers, or strangers to build self-efficacy	"…I think I can do it as well." (Male, 16)	Beginner micro-vlogs; graduated PA tasks
Positive	Companionship	+	Peers, family, acquaintances	Doing PA together (offline/online) to sustain engagement	"…we feel like we are running together; this is much better than me running alone." (Male, 16)	Real-time buddy features in apps
Positive	Competition	+	Peers, classmates	Step counts or logs stimulate comparison and motivation	"…guys tend to compete for a higher number of steps; they are keen to see who ranked last." (Female, 16)	Gamified challenges with safeguards
Negative	Misinformation	–	Influencers	Unrealistic routines or harmful diets undermine healthy PA	"…I watched many slimming methods… life makes me feel painful." (Female, 16)	Verified creator badges; evidence-based tips
Negative	Distraction	–	Peers/ platforms	Chatting/scrolling displaces PA time	"…then I just don't want to move anymore." (Female, 18)	Focus modes; time-budget prompts
Negative	Appearance focus & stereotyping	–	Online strangers/ communities	Body image pressures and gendered assumptions restrict PA choice	"…sports like skateboarding belong to the male domain, while a female should do yoga." (Female, 18)	Inclusive messaging; de-emphasize appearance metrics

Table 1: Themes, subthemes, directions, tie types, operational definitions, representative quotes, and implications

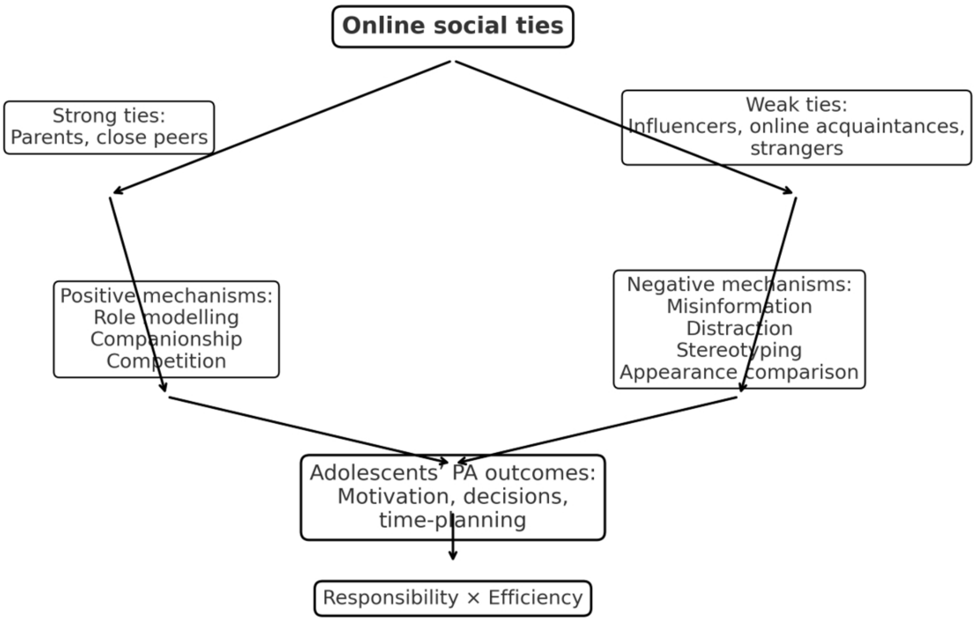

Figure 1: A conceptual model for illustrating the findings

Social Support

Informational Support and Emotional Support from Role Models

The participants identified several persons who influenced their PA behaviour, such as peers, parents, social media influencers, and online friends. The participants described how peers could act as role models through their online social media behaviour. Since they provided guidance, teaching skills, and set good examples in terms of being physically active, participants reported that their peers played a crucial role and helped them both informationally and emotionally. For instance, participants mentioned senior peers from the same school often send them helpful guidance comments: *"From my senior class, I knew some students, they have some advice to help me do some skillful movements in a sport, and usually offer this help through a comment on the sharing posts in my social media account" (Male, 16 years old).*

Participants further reported feeling more enthusiastic and motivated to engage in PA and wanting to imitate their peers' PA habits when they received videos made by their peers recording positive changes, processes, or results of PA experienced by their peers, as can be seen in the following quotes:

"He lost weight successfully after I watched this comparison in his videos. I feel confident to exercise more, I think I can do it as well" (Male, 16 years old).

"…when I saw a fitness blogger about my age doing push-ups every day, I felt like maybe I could start small too." (Male, 14)

"In videos about my peers, they all look very athletic, energetic, and you want to participate, or you really want to go out and watch them exercising" (Female, 16 years old).

"Sometimes my friends will share some people who play basketball, and they play with nice techniques, that sportive atmosphere makes me want to go out to play basketball now" (Male, 17 years old).

In addition to known offline peers and friends, participants mentioned that online friends, whom they knew from social media, were also supportive informationally and emotionally, as they are usually like-minded people who share uncommon forms of PA interests with participants, as one participant said:

"The sport or PA I'm good at is kickboxing. I would share related content on social media. Then I could receive some suggestions and support from a professional player of a similar age, and they could tell me, for instance, a specific movement I didn't do very well. I speak with them frequently; I think one of them, a girl, my friend, like someone you can meet online for mutual improvement in some skills, but like a friend. I can almost get a personal trainer online; that's what I think I got the most from social media using for PA" (Female, 16 years old).

Furthermore, participants also reported how they perceived social media influencers as role models. Participants mentioned they appreciated fitness influencers' vlogs (a series of videos being posted under a theme) that present PA achievement, a model for a healthy and active lifestyle, or instructional PA vlogs. For instance, participants noted how influencers helped them gain additional skills through their instructional vlogs that school education usually didn't offer: *"There are a lot of videos that are really funny, like dancing to a pop song, but the influencers change the original moves of the dance of the song into a new series of very simple moves, just for exercising, not for perform on stage, people like me who are not good at dance can follow and train my body, I think these contents are very attractive, which do not usually appear in PE classes"* (Female, 17 years old). Also, the participants stated that they perceive these vlogs to be especially beneficial when they are attempting to learn something new about a sport or PA as a beginner, as can be seen in the following quote.

"You can also search for some basic body movement-related skills you need when you plan to go to the gym daily. You can also see content posted by these influencers, such as videos titled "What should a beginner do when you first go to the gym?" These vlogs are of great help to us, gym beginners" (Male, 16 years old).

Participants also mentioned how fitness influencers not only motivated them to engage in PA but also helped them to plan their day accordingly acting as a practical guide for after-school PA time arrangement, as one participant said: "*Usually I don't know what PA I should do after school before, but when the trend of PA-related influencers starts, and then I start to watch their vlogs, then I start to arrange my time more tightly, and doing a lot of things actively, I think their videos help me to have an active attitude of arrange my time, make me more motivated to become more self-organized, of course, I'm being more physically active than before" (Female, 18 years old).*

Similarly, a female participant talked about the effects the fitness influencers associated with increased PA behaviour and an active lifestyle such as enhanced attitude and mood as can be seen in the following quote, *"When I see the good and positive side that sport brought to the vlogger, for instance, become more optimistic towards life, I will make my decision immediately like I want to be a person like them" (Male, 19 years old).*

At last, some participants mentioned how they perceived their parents as role models who helped them with both their social media presence and exercise-related advice, particularly in relation to their videos. For instance, a female participant said that her father often messaged her with professional pieces of advice: *"My dad will look carefully at my steps (in my video clips), like how I run. He could see my mistake clearer in my videos and would talk to me on social media. My mom helped me shoot these videos" (Female, 16 years old).* Another participant similarly mentioned how her father gave her skill-related advice after watching her badminton videos *"My father is more professional than me in terms of playing badminton usually I will let others shoot a video of me playing badminton and say to my father, especially when I'm a beginner, he will tell me how I should wave the racket because he cannot always by my side watch me play, so I think social media are useful at this time" (Female, 19 years old).*

Companionship and Competition through Online Social Tools

This sub-theme summarizes how participants recognized that social media helped them to achieve mutual companionship for exercising, whether in person or virtually. They found that social media not only allowed them to plan exercises with their friends in person but also provided ways for them to achieve virtual companionship with their peers which were explained in the following quote: *"One of the social media functions I use is running together with both two people turning on voice chat (a function usually embedded within instant messaging) and talking to each other in real-time; we will talk while we run on ourselves in different places, this can actually encourage our physical activity behaviour efficiently. In this way, we feel like we are running together; this is much better than me running alone"*(16 years old, Male).

Participants noted the virtual companionship they experienced through online PA events, which motivated them to engage in PA virtually. For instance, a participant described how other people participating in the online virtual PA community motivated her dedication to PA activities alone:

"People would type things onto the screen like 'this one is difficult, let's do this together,' sometimes when you don't

want to persist when you look at the screen, you will find what people said are actually interesting, then you would persist to the end of the course, and several days after, you will have a very strong sense of achievement, like you finish a thing, a group activity with many people, and they are all strangers actually" (Female, 16 years old).

According to the participants, the online communication between family members about PA also provided a sense of companionship. It positively influenced the family environment regarding sports and PA, as this participant said: *"Usually when I go home after school, or during the weekend, my parents and I will go outside for a while for exercising. During this time, we will use cellphones to record our exercise data, like how many calories we consume, something like that, we will share these records with family members through social media, sometimes I take pictures of my parents exercising and send pictures to my parents on social media, I think we know each other's sport status better in this way, and I think my parents are happy when they see me exercising a lot every day"(Male, 17 years old).*

Participants reported that participating in PA-related online competitions with peers could motivate them to engage in PA on their own during out-of-school time. For instance, participants said sharing personal exercise logs and data (such as running miles, calorie consumption, heartbeat rate, step counts, etc.) on social media can be an exciting and motivating way to initiate and maintain PA behaviour while interacting socially online through competitions, as the following participants described in detail:

"My friend and I would share exercise logs on social media; we would see each other's data every day; I would buy a gift for her if she achieves a certain number. In this way, we can persist in participating in physical activity together" (Female, 18 years old).

"When using step counting apps like Werun, guys tend to compete for a higher number of steps; they are keen to see who ranked last. I think this actually helps them walk more" (Female, 16 years old).

"I know that people in our class often compete for the step numbers; someone even ties their cell phone onto their pet dogs to have more walking step numbers. I think this makes us more active" (Male, 16 years old).

Perceived Barriers

Peer's Distraction

Some participants reported how maintaining and being active in online social relationships could also negatively influence their out-of-school PA motivation, decision-making, and planning. For instance, a few participants noted that spending time online chatting with peers and friends sometimes also decreased their PA as described through the following quotes: "*When my friends send me messages, or share some videos online to me, then I just don't want to move anymore" (Female, 18 years old); "Sometimes when I had the plan to do PA later after school, then my friends send me some funny videos and chatting with me, then I will just chatting with her, and then I miss the time planned for doing PA" (Female, 16 years old). Similarly, another participant added: "I wanted to do some exercising after school, then my friend sent me something online, then I chatted with her, at last, I just forgot that I wanted to do exercise" (Female, 19 years old).*

Negative Impact of Fitness Influencers

Especially older adolescent participants (ages 17-19) emphasized the potential negative influences of fitness influencers. According to them, the primary downside of following social media influencers is that they may promote exercise routines that are not suitable for everyone, potentially causing psychological and physiological harm. *"Generally speaking, social media marketing strategies aim to use a simple way to have a bigger influence. So did the influencers. If you follow their rules, there will only be two possible results. One result is that you may fail to achieve the results described on social media for doing a specific physical activity or sport. That will cause a psychological discrepancy, and you may suspect yourself. Another result is that, if you work out too intensively, it will cause real physical hurt to your body to some extent" (Male, 16 years old).*

Particularly, male participants explained how they were worried that they could not follow the exercise instructions because they were not as well-trained as the fitness influencers: *"I would also think about my personal fitness, like if my body could allow me to do the same sport as the influencers did or not? If I feel this sport is not suitable for me, I will just quit" (Male, 19 years old).*

"You can see a muscle man teaching you what you could do to improve your fitness very often, like doing much intensive exercise. But I think people like me can hardly insist on that amount of exercise every day because I'm not well-trained like him; I will be too tired to follow his steps" (Male, 19 years old).

Some participants specifically pointed out that the instructions of fitness influencers could be problematic and might lead to feelings of stress and anxiety in learning, especially when unhealthy eating recommendations accompany exercise videos. One participant described this experience as follows: *"I watched many slimming methods, like running how many miles every day but only eating cucumber and drinking water; I definitely cannot do that; just imagine that life makes me feel painful; also, I know that method would definitely work" (Female, 16 years old).* As a result of stressful learning, participants mentioned that they gradually lost interest and enjoyment in PA: *"I think it's like the butterfly effect, the more I care about these details and struggle to do perfectly the same as shown in videos, the more I feel anxious and couldn't reach my purpose of doing PA, then sooner or later I would give up" (Male, 17 years old).*

Online People's Stereotyping of Activities, Online Comparison, and Unfriendly Feedback

Participants also expressed the negative impact they experienced from online people on their PA behaviour. They believe that user comments and promoted content can influence one's personal PA choices, decisions, and motivation, as social media appears to be a large community that connects everyone online. Some participants pointed out that promoting appearance comparisons in exercise-related content and stereotyping of certain types of PA based on gender contributed negatively to the online environment of PA, as the following participant explained:

"I think online people have a strong gender stereotype about PA types. They believe that sports requiring more physical stamina, such as skateboarding, kickboxing, and football, are traditionally considered male-dominated. At the same time, activities such as dancing and yoga are often viewed as more suitable for females. Many people have these opinions, and a lot of people care about this, and this stereotype limits my PA choice" (Female, 18 years old).

Another aspect related to online appearance-related content is the use of filters. One participant reported how the use of filters by social media users bears the risk of unrealistic appearance goals that cannot be reached by exercising only, as she explained in the following:

"People usually post their pictures with filters and make themselves look nicer. Sometimes it can motivate people to focus more on their body image, such as through sports. Still, if this content is too much, I think people like me will not do more sports to become slimmer. Still, I will just try to eat less and less, stay at home, or some girls may go on some medicine for slimming instead of exercising, because it's much easier, compared to exercising for sweating, I think" (Female, 19 years old).

In a similar vein, some participants further mentioned that online comparisons, either in terms of appearance or competition comparisons with other users, made them overlook their initial motivation of PA and could therefore decrease PA enjoyment, as explained in the following two quotes:

"The negative effect of social media is that we may pay too little attention to the essence of doing PA, for instance, why we do PA? We often focus on or pursue something superficial, or we use social media just to compare and compete with others. For instance, we might not appreciate what we have or learn from participating in a sport. Otherwise, we simply want to look better than others on social media" (Male, 16 years old).

"…sometimes I scroll and see girls my age with perfect abs, then I feel bad and don't even want to join PE class." (Female, 15)

"Some people go to the gym but only to take selfies, and don't really do sports or PA I think they will post on social media to get more 'thumbs up' instead of enjoying themselves or wanting to become healthier" (Male, 18 years old).

At last, participants brought up the issue of unfriendly comments about their appearance (haircut, body shape, weight, movement, etc.) from unknown social media users during online interactions. When these comments appeared after the participants posted PA-related content, participants felt that these comments could be a distraction for them from enjoying PA and achieving their goals, as a participant described in detail:

"When I see online people's negative comments about what PA others doing, if that PA is also what I like to do, or similar to my interested PA, those negative comments is a blow to my motivation and confidence, for instance, I like a specific pop dance, then I see on social media about people's comments like, why this dance looks so ugly? If that's some kind of sport that I'm not interested in, I will not care about the negative comments, but I am the kind of person who cares about others' opinions, and I will think about what they said" (Female, 16 years old).

DISCUSSION

The present study provided the first exploration of Chinese adolescents' social ties in social media and how this impacted their PA behaviour positively and negatively. Besides strong ties, such as peers and parents, we found that weak ties, or peripheral ties like fitness influencers and online acquaintances, are also perceived to have both supportive and sabotaging influences. While role modelling, companionship, and competition from them were generally perceived to provide informational and emotional support, fitness influencers, peers, and online individuals were also perceived to influence PA negatively. The importance of this influence was consistent for younger and older adolescents, as well as both genders in this study.

Positive role modelling, companionship, and competition from online social ties emerged as important ways of social support to PA. These three ways of social support have also proven effective in increasing motivation for behaviour change in the PA domain in an offline context, as found in previous research (Sohn and Lee, 2007). This social support found online provided the motivation needed to start PA, in some cases, when participants were sedentary, or helped through informational and emotional support. Therefore, lifestyle interventions that emphasize supportive realities can potentially engage more weak ties in healthier behaviors, especially among adolescents after school or during leisure time. When they are physically apart from their peers and parents, online social ties could play an important role in motivating their PA conduct on their own; however, existing efforts on increasing adolescents' PA behaviour have focused primarily on their offline strong social ties like family and peers.

This study also explained that both types of social ties uniquely had motivating sides for participants with diversified PA. For instance, while fitness influencers could help participants learn certain PA knowledge as a beginner, peers could start competing with participants, e.g., more walking steps. These patterns support the idea that different social ties serve different functions (Fingerman, 2009) and help to explain the benefits of having diverse social ties (both close and peripheral) to psychological and physical well-being.

Researchers argue that a more diverse social network co-occurs with engaging in a greater variety of behaviors throughout the day. Being socially integrated, by definition, means being involved with diverse people engaging in diverse behaviors (Lee et al., 2018). In this study, we found that this engagement and encounter with others occurred in an online environment. It was demonstrated that diverse online social integration and engagement, including both strong and weak ties, could provide participants with more opportunities to be involved in PA when they did not have a partner in the offline world with whom to conduct PA. For instance, attending online training classes with online PA communities was more motivating than attending them alone. Findings from the current study suggest that this virtual PA co-participation with online people may illustrate that this mechanism also exists in online social ties.

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In participants' weak ties, social media fitness influencers were identified as role models for PA behaviour. Previous studies of social media fitness influencers have also indicated that they may be an important digital type of health communicator who can influence health behaviors (Pilgrim et al., 2019). While this study indicated that participants mainly received informational and emotional support through role modelling, they also mentioned the influencers' trustworthiness, particularly their source credibility, which appeared to be particularly important for their attitude toward social media fitness. This finding aligns with previous research that identified trustworthiness as a central influencing characteristic (Lou and Yuan, 2019). Although the motivating power of influencers had an impact on the intention to PA, the credibility of fitness influencers remained a concern for participants.

The commercial nature of the PA crash course and the credibility of the fitness influencers participants identified can be related to previous studies about social media literacy. Social media literacy focuses on the interactions among users of social media, whether with friends, peers, or celebrities, as well as developing the skills to examine the messages underlying commercial media advertising, including health and fitness content, seen on social media (McLean et al., 2019). Therefore, although many of the health-focused influencers lack professional accreditation and may post misleading nutrition advice that is not evidence-based (Easton et al., 2018) and therefore may mislead adolescents' PA conduction, it can be seen that adolescents' fitness influencer-related literacy could serve as a buffer for these negative influences.

Participants also expressed concerns about appearance-based online comparisons. For instance, they found that pictures using filters to show unrealistic appearances, along with online appearance comparisons, could make them less focused on enjoying PA and more likely to change their body image through a healthier, dedicated approach, such as doing PA. Indeed, previous research has demonstrated that social media usage is associated with greater body image concerns (Fardouly et al., 2017), while fitspiration content (a portmanteau of the words 'fitness' and 'inspiration'), or appearance-promoting related content has the potential for considerable positive influence on female's health and well-being in terms of promoting exercise engagement, however, it should also consider the potential negative influences. In this study, although participants didn't mention that appearance is the reason for them to exercise, they suggested a relationship between their PA motivation and appearance. In fact, a large proportion of the content promotes exercise to improve appearance (Carrotte et al., 2017). Evidence suggests that young women who use appearance-related reasons as motivation to exercise, rather than health-related reasons, are at an increased risk of body dissatisfaction (Prichard and Tiggemann, 2008).

IMPLICATIONS FOR EDUCATIONAL RESPONSIBILITY AND EFFICIENCY

Our qualitative findings highlight that weak-tie infrastructures (e.g., public influencer content, open fitness communities, app-based challenges) efficiently deliver motivation through role modelling, companionship, and competition. For example, participants described how daily step-count rankings in WeRun or watching influencers' training videos encouraged them to persist with PA despite limited family support. This shows how large-scale, low-cost social cues can extend adolescents' activity beyond immediate strong ties (Jia et al., 2025; Wang et al., 2024). However, our data also reveal clear risks: several adolescents reported exposure to misleading diet routines or appearance-driven comparisons that reduced motivation or caused stress (Engel et al., 2024). Addressing efficiency, therefore, requires responsible design—such as verified expert badges, age-appropriate progression, and algorithmic down-ranking of harmful content (Aschwanden et al., 2024). Furthermore, schools could integrate moderated step-count competitions and buddy tasks to leverage efficient social mechanisms while minimizing harmful comparison (Bull et al., 2020; CDC, 2024). Developers could incorporate features adolescents explicitly valued in our focus groups—such as private feedback loops and real-time companionship—to scale support without amplifying social pressure (Zhang et al., 2024). Policymakers, in turn, should establish responsibility frameworks for platforms hosting adolescent PA content, ensuring alignment with WHO guidelines (Bull et al., 2020). This would allow adolescents to benefit from efficient peer-driven encouragement while being safeguarded against misinformation and negative stereotyping.

STRENGTHS AND LIMITATIONS

This study focused on the perceived impact and subjective experiences of online social ties on participants' PA. It's crucial to note that various factors could impact how individuals perceive the influence of online social ties, such as the number of friends, the level and emotional content of interactions, self-disclosure, communication competence, and social comparison to other users. Moreover, this study only included Chinese adolescents as the research population, which may limit the generalizability of the results to other cultures.

Despite some limitations, this study has several strengths. Firstly, it is among the earliest to investigate the impact of online social ties beyond family and friends. Secondly, we identified social support, as well as in what ways social support was perceived to influence adolescent PA, as well as stress factors. Lastly, this study enriches the understanding of online influencing agents on PA. These influences can be applied and generalized in everyday life, particularly when face-to-face social support is not readily available.

CONCLUSION

These data suggest that multiple social relationships in the online social networking world influence adolescents' PA. Apart from strong ties, online social ties incorporate various weak ties that could also influence adolescents' PA. When designing social media interventions aimed to create an impact on PA, researchers and practitioners should consider the unique roles and interactions of various online social ties. Especially when adolescents lack a partner in the offline world to conduct PA together, the supportive role of virtual companionship was highlighted. This was described as motivating when attending online PA sessions as well as when running alone to connect virtually.

Nevertheless, negative aspects of PA behaviour, such as the stereotyping of activities and the focus on appearance, were mentioned. These aspects could be addressed in adolescents' PE in school. Future research should consider testing the strategies on adolescents' PA behaviour, which were suggested in the present article that addressed multiple ways of social support, for instance, through online role modelling, online companionship, and online competition.

DATA AVAILABILITY STATEMENTS

The datasets analyzed are available in a publicly accessible repository named figshare (https://figshare.com) and can be found here: https://doi.org/10.6084/m9.figshare.24465607.

CONFLICT OF INTEREST

Conflict of interest: *The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.*

AUTHOR CONTRIBUTIONS

MC was responsible for study design, data acquisition and interpretation, and manuscript preparation, and finalised the manuscript. AF and YD made substantial contributions to the manuscript and provided edits. AKR and CK provide valuable feedback, ensuring that the accuracy and integrity of any part of the work are appropriately investigated and resolved. YD approved the final manuscript.

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Full research paper

THE ROLE OF SPATIAL ANXIETY IN THE RELATIONSHIP BETWEEN MATHEMATICS ANXIETY AND SPATIAL REASONING

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ABSTRACT

This study explored the connection between mathematics anxiety and spatial reasoning, examining potential mediating and moderating effects of spatial anxiety, as well as the roles of grade level and gender. A cross-sectional survey was conducted with 477 elementary school students in Jakarta, selected through convenience sampling. Participants included 185 from grade 4, 179 from grade 5, and 113 from grade 6, with a gender distribution of 51.4% male and 48.6% female. Mediation and moderation analyses were performed using the PROCESS macro in SPSS. The findings revealed that (1) mathematics anxiety has a significant negative direct effect on spatial reasoning; (2) spatial anxiety mediates the relationship between mathematics anxiety and spatial reasoning; and (3) the strength of this relationship varies according to levels of spatial anxiety. These results suggest that students with higher mathematics anxiety may experience greater difficulty with spatial reasoning tasks. Accordingly, interventions targeting both mathematics and spatial anxiety could enhance spatial reasoning among those with elevated mathematics anxiety. Beyond these implications, the findings underscore the importance of improving educational efficiency through targeted interventions and strengthening educators' responsibility for addressing affective barriers that limit the development of spatial reasoning skills.

KEYWORDS

Educational efficiency, mathematics anxiety, responsibility in education, spatial anxiety, spatial reasoning

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Highlights

- *Mathematics anxiety has a negative and significant direct effect on spatial reasoning.*
- *Spatial anxiety mediates the relationship between mathematics anxiety and spatial reasoning.*
- *The relationship between mathematics anxiety and spatial reasoning may vary depending on the levels of spatial anxiety.*

INTRODUCTION

Geometry and spatial reasoning in the development of mathematical knowledge are interrelated (Battista, 2007; Clements and Battista, 1992) and play a crucial role in interpreting and reflecting on the physical environment. Geometry and spatial reasoning are not only useful for the development of both but also provide support for general mathematics performance (Lowrie et al., 2016) and learning other mathematical disciplines, such as arithmetic (Zhang and Lin, 2017), as well as other fields of science, such as science, technology, and engineering (Gilligan et al., 2017; Uttal et al., 2013).

In contrast to the recognized importance of geometry and spatial reasoning, several studies have reported the need to emphasize spatial reasoning in mathematics learning due to outcomes that fall short of expectations (Clements and Sarama, 2011; Hasanah et al., 2024; Mulligan, 2015). Hallowell et al. (2015) focused on identifying the spatial reasoning of first-grade students in constructing and decomposing geometric figures. However, the identification results highlight the difficulties students encounter, particularly in connecting 2D diagram lines with 3D boundaries. It is likely that these problems occur because spatial reasoning does not have an explicit place in the mathematics curriculum (Wai et al., 2009). In fact, given the important role that spatial reasoning plays, it should make sense that geometry and spatial reasoning have an important place in the school mathematics curriculum. Hejnová et al. (2024) also emphasized in their findings that geometric abilities, especially spatial ones, are integral to the thinking skills required in problem-solving.

The basis of most geometric thinking is spatial reasoning, which involves the ability to perceive, analyze, and mentally manipulate objects, visualize their images, and understand their interrelationships (Battista, 2007). Another opinion provides a definition related to spatial reasoning, which is the process of perceiving, collecting, creating, and communicating objects in two or three-dimensional space to conclude from various information collected, which involves three objects with spatial components, including mental rotation, spatial visualization, and spatial orientation (Lowrie et al., 2016; Lowrie and Logan, 2018). Examples of spatial reasoning include locating, orienting, decomposing/rearranging, balancing, diagramming, symmetry, navigating, comparing, scaling, and visualizing (Mulligan et al., 2018).

The rationale highlights the importance of spatial reasoning in problem-solving, decision-making, and other cognitive processes that require an understanding of space and spatial relationships (Duffy et al., 2024; Munoz-Rubke et al., 2021). Therefore, educators should prioritize the development of spatial reasoning skills in their teaching practices to ensure that students are equipped with the necessary tools to navigate the complex world around them. As a first step, an analysis of spatial reasoning and its relationship to mathematics learning is necessary to inform decision-making during learning activities (Ishikawa and Newcombe, 2021).

Spatial reasoning is considered part of cognitive abilities and related to problem-solving (Altıner and Doğan, 2018). It turns out that, apart from being closely related to cognitive abilities, spatial reasoning is also closely related to emotional (affective), biological, and experiential factors (Ramirez et al., 2012). Furthermore, Ramirez et al. (2012) mention that affective factors in spatial reasoning are an interesting focus of study and are still rarely found in the literature.

LITERATURE REVIEW

Spatial Reasoning and Mathematics Achievement

The term "spatial reasoning" is often used interchangeably with other related terms, such as "spatial thinking," "spatial ability," "spatial sensitivity," "spatial intuition," "spatial perception," and "spatial intelligence." In this section, each overlapping term will be clearly defined and then used as a guideline for naming the terms. The consensus regarding the definition of spatial reasoning centers on a range of mental processing abilities that enable the analysis, manipulation, and generation of mental representations of visual, spatial, and graphic information (Clements and Battista, 1992; Diezmann and Lowrie, 2012; Uttal et al., 2013). Spatial thinking is another type of human cognition, similar to verbal and numerical cognition, involving spatial relationships (Bednarz and Lee, 2019; Bednarz and Lee, 2011). Furthermore, spatial ability is defined as a separate intellectual concept that encompasses spatial relationships and spatial visualization factors (Pellegrino et al., 1984). Spatial sensitivity refers to the ability to detect or respond to differences or patterns of change (Lilburne and Tarantola, 2009); this term is more commonly used in the field of geography. Lastly, spatial intuition, as illustrated by Raftopoulos (2002), refers to an individual's ability to visualize objects related to spatial concepts. Based on several definitions of the similarities between the terms used, this study employs the term "spatial reasoning" because it provides a clearer understanding of the aspects of each construct that are expected in this study.

Different approaches exist for classifying spatial reasoning dimensions. Clements and Battista (1992) differentiate between two dimensions: spatial visualization and orientation. Others suggest a three-dimensional approach, including spatial visualization, orientation, and mental rotation, to adapt primary and secondary school curricula (Lowrie and Logan, 2018; Ramful et al., 2017). Spatial rotation involves mentally manipulating and rotating objects or images in space, transforming their orientation. Spatial visualization involves creating and manipulating mental images, whereas spatial orientation involves understanding and determining spatial relationships in relation to one's body orientation.

The relationship between spatial reasoning and mathematical achievement has been extensively studied and acknowledged in the literature. Cognitive skills involved in spatial reasoning, such as mentally manipulating objects in two and three dimensions, are crucial for understanding and solving complex mathematical problems. Resnick et al. (2020) and Cheng and Mix (2014) found a consistent relationship between spatial reasoning and mathematical achievement. They found that individuals with stronger spatial reasoning skills perform better in mathematics. They emphasize the importance of incorporating spatial reasoning activities and interventions in mathematics education to enhance students' understanding and problem-solving abilities. This is also emphasized by Prokýšek and Rambousek (2013), who state that spatial reasoning is directly related to the ability to absorb information; in other words, students with good spatial reasoning will find it easier to learn.

Mathematics Anxiety and Spatial Anxiety

Mathematics anxiety and spatial anxiety are two distinct types of anxiety experienced by individuals in relation to mathematics and spatial tasks. Mathematics anxiety involves fear, tension, and apprehension when faced with mathematical tasks, leading to negative emotions and avoidance behaviors (Harari et al., 2013; Suci and Purnomo, 2016; Zhang and Wang, 2020). Factors influencing mathematics anxiety include previous negative experiences, fear of failure, societal pressure, and a lack of confidence in mathematical abilities.

Spatial anxiety, on the other hand, refers to the discomfort individuals may feel when engaging in spatial tasks or dealing with spatial information. Factors such as lack of spatial reasoning, limited exposure to spatial tasks, or negative experiences related to spatial activities can influence spatial anxiety (Ramirez et al., 2012; Şanli, 2024). Although they are distinct, there may be some overlap in their underlying factors and impact on performance. For example, individuals with high levels of mathematics anxiety may experience heightened spatial anxiety when engaging in tasks involving spatial reasoning, such as geometry problems (Ferguson et al., 2015).

Spatial Reasoning and Anxiety

Mathematics anxiety is a significant concern for researchers due to its correlation with students' achievement in learning mathematics. It is considered a psychological construct that can predict lower math performance (Lukowski et al., 2019) and negatively impact cognitive processes, including spatial reasoning. Students experiencing high math anxiety tend to exhibit increased brain activity in the regions associated with threat detection (Schenck, 2022), leading to earlier feelings of anxiety. Consequently, mathematics anxiety can deplete cognitive resources, hindering effective engagement in spatial reasoning tasks and resulting in decreased performance in solving spatial problems.

In an empirical study, Malanchini et al. (2017) discovered a negative relationship between spatial anxiety and spatial reasoning. This means that an increase in spatial anxiety is associated with a decrease in spatial reasoning. Similar findings were also reported in research by Alvarez-Vargas et al. (2020), indicating that anxiety can interfere with mental rotation performance —a crucial aspect of spatial reasoning. Lourenco and Liu (2023) explored the impact of anxiety and motivation on spatial reasoning, both of which can influence performance in spatial tasks. Likewise, Ramirez et al. (2012) found that spatial anxiety is negatively correlated with spatial reasoning, a relationship similar to that between mathematics anxiety and mathematical performance.

The research conducted by Ramirez et al. (2013) suggests that children, even at a young age, tend to experience feelings of nervousness when confronted with spatial activities. Moreover, the findings suggest that feelings of nervousness associated with spatial activities can impact mental rotation ability, particularly among girls with high working memory. Understanding these patterns can contribute to a deeper understanding of the factors influencing spatial cognition and the development of interventions to support children in overcoming spatial anxiety and enhancing their spatial reasoning. Additionally, according to Blair (2010), it is crucial to consider how gender variations affect the development of spatial reasoning and to employ strategies that are tailored to each gender's traits. For example, girls tend to prefer manipulative games that emphasize social aspects, whereas boys tend to favor games that focus on competition. It's interesting to note that only girls showed this connection between working memory and spatial anxiety. However, a study by Wong (2017) on 182 toddlers in Hong Kong found an indication that spatial anxiety moderated the space-math link, but the effect differed for boys and girls. The spatial reasoning of boys is not relevant for computing at high levels of anxiety; the role of girls' anxiety in spatial mathematical relationships is less clear. These findings provide basic evidence of the relationship between spatial mathematics, including extrinsic spatial reasoning (targeting accuracy), and have implications for intervention programs. The study is supported by strong longitudinal and cross-sectional evidence that spatial reasoning and mathematical abilities are associated with childhood (Atit et al., 2022; Gilligan et al., 2017).

There is little literature that examines spatial reasoning associated with anxiety factors, making both of them interesting to study in more detail. This is, as stated by Ramirez et al. (2012), that understanding anxiety and its relationship to spatial reasoning can provide new ways of thinking about individual differences in spatial reasoning, ultimately leading to interventions designed to reduce anxiety and increase levels of spatial reasoning and achievement in student performance in STEM disciplines. Moreover, there are still very few empirical studies on spatial reasoning and mathematics anxiety in the context of Indonesian students, including the appropriate measurement tools, descriptions of student tendencies in Indonesia, and their implications. No evidence of intervention refers to the research results of these two variables. Therefore, based on these problems, researchers try to examine more deeply how these two variables are described in the research results.

The relationship between mathematics anxiety and spatial reasoning has been extensively studied. Still, little research has explored the potential changes in magnitude, direction, and type when considering mediating or moderating variables. This study aimed to investigate whether spatial anxiety is mediated by mathematics anxiety or if the relationship differs depending on its level. To examine the mediation or moderation model, grade and gender covariates were used to statistically control for the effect. The questions in this research include:

1. How does mathematics anxiety affect spatial reasoning? (Hypothesis: the higher the mathematics anxiety, the lower the spatial reasoning)
2. In addition to the direct effects above, is there a significant indirect effect between mathematics anxiety and spatial reasoning, through spatial anxiety? (Mediation hypothesis: the higher the mathematics anxiety, the higher the spatial anxiety, and the lower the spatial reasoning)
3. How can the level of spatial anxiety condition the relationship between mathematics anxiety and spatial reasoning? (Moderation hypothesis: the higher the level of spatial anxiety, the higher the negative relationship between mathematics anxiety and spatial reasoning).

MATERIALS AND METHODS

Context and Participant

This cross-sectional survey study aimed to collect data from elementary school students in Jakarta using convenience sampling. The sample included 477 participants, with 185 in grade 4, 179 in grade 5, and 113 in grade 6. Of the total participants, there were 245 males and 232 females. The gender distribution was balanced, with 51.4% male and 48.6% female, ensuring representation from both genders.

This research was conducted with the official permission of the elementary school, as evidenced by a research permit letter. After completing the research activities, the researchers also received a certificate as proof that the research had been conducted at the school in accordance with the applicable procedures. We did not undergo the ethical assessment procedure by an ethics review board because social science research ethics boards are not yet established in Indonesia, and this procedure is not commonly practiced for social science research in the country. Nevertheless, Participants were given the freedom to choose whether to participate before completing the questionnaire, and no personal or school information was disclosed.

Measure

Spatial Reasoning

To assess this ability, we have adapted a spatial reasoning test instrument based on the work of Ramful and his colleagues

(Ramful et al., 2017). The test measures three key factors: mental rotation, spatial orientation, and visual orientation. Mental rotation refers to the ability to mentally manipulate objects in three-dimensional space. Spatial orientation involves understanding one's position in relation to other objects in space. Finally, visual orientation refers to the ability to mentally rotate two-dimensional images.

Ramful et al. (2017) employed factor analysis to identify the most effective items for measuring the spatial reasoning test, which initially contained 45 items and was subsequently reduced to 30 items, with each factor consisting of 10 items. Although three of these forming factors do not have a high level of reliability, the thirty items as a whole have a Cronbach's alpha value of 0.849. The discriminating power of the three factors that form spatial reasoning itself ranges from 0.27 to 0.48, indicating that the discriminating power of each factor is medium to high. Table 1 below shows the indicators of spatial reasoning ability tests.

Factor	Item characteristics	No.	Number of items
Mental Rotation	• Determines the result of the rotation of a 2D and 3D object. • Distinguish between reflection and rotation	3, 5, 7, 8, 14, 15, 18, 20, 24, 28	10
Spatial Orientation	• Figuring out where an object is in relation to the observer • Examining maps from various angles • The process of determining a point's cardinality when the north is not in the vertical upright direction • Recognizing an object's orthogonal views	1, 4, 9, 11, 12, 16, 22, 25, 27, 29	10
Visual Orientation	• Visualize the result of folding/unfolding a given configuration • Constructing a solid from a given net and vice versa • Matching pieces and parts, finding symmetry in an object • Reflecting an object.	2, 6, 10, 13, 17, 19, 21, 23, 26, 30	10
Total			30

Table 1: Framework and Indicator of Spatial Reasoning Ability Test

A multiple-choice test consisting of 30 items is used to assess this skill. The scoring system awards one point for each correct answer and zero for incorrect responses. The following is an example of an instrument that has been adapted into Indonesian by researchers.

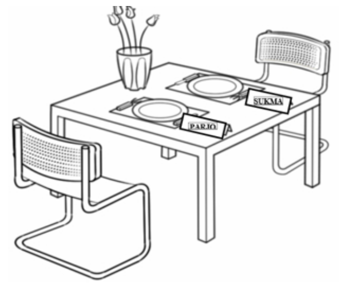
Original instruments	Adapted instruments
The seating positions of Kate and William are shown below.	*Posisi tempat duduk Sukma dan Parjo ditampilkan di bawah ini* [Sukma and Parjo's seating positions are shown below].
	
In which position is the flower vase from Kate's view? a. To her right b. To her left	*Dimana posisi vas bunga dari pandangan Sukma?* [Where is the flower vase from Sukma's point of view?] *a. Di kanan Sukma* [To Sukma's right] *b. Di kiri Sukma* [To Sukma's left]

Table 2: Example of Spatial Reasoning Instrument

Mathematics Anxiety

We adapted the scale developed by Harari et al. (2013) to measure mathematics anxiety. This scale has three factors: negative reactions, numerical confidence, and worries. There are 12 items on this scale with seven positive statements and five negative statements. In the study, children answered the questions using a 4-point emoji sliding scale, where each point was associated with a specific coding scheme for negative and positive items. The negative item was coded so that "yes" = 4, "kind of" = 3, "not really" = 2, and "no" = 1. The positive item was coded so that "yes" = 1, "kind of" = 2, "not really" = 3, and "no" = 4. The maximum score that students can achieve is 48, and the minimum score is 12. The mathematics anxiety questionnaire item factor is presented in Table 3.

Factor	Item	The number of items	Item Sample
Worries	2, 3, 6,	3	In math class, I am scared.
Negative Reactions	4, 8, 9, 12	4	My tummy hurts after doing math.
Numerical Confidences	1, 5, 7, 10, 11	5	I like being called on in math class.

Table 3: Indicator of Mathematics Anxiety Questionnaire

Spatial Anxiety

In the study, the researchers retained the original questionnaire instrument developed by Ramirez et al. (2012), which consisted of eight items. However, we modified the response scale by implementing a 4-point emoji sliding scale. The scale included four different emojis to represent the response options: normal (😃), confused (🤔), nervous (😬), and afraid of being wrong (😨). The maximum score that students can achieve is 32, and the minimum score is 8.

Data Analysis Procedures

We use content validity and face validity, which were previously translated from the original instrument into Indonesian. These translations were reviewed by two experts to ensure accuracy and cultural appropriateness. Additionally, pilot testing was conducted to assess the clarity and comprehensibility of the translated instrument among 10 Indonesian elementary school students. Both of these validations indicate the feasibility of using the mathematics anxiety, spatial anxiety, and spatial reasoning instruments for data collection.

The researcher conducted a reliability test to determine the reliability of the instruments used in Indonesia. The Cronbach's Alpha value was used to assess the reliability of the spatial reasoning and anxiety instrument. A Cronbach's Alpha value greater than 0.60 is considered acceptable reliability, as agreed upon by Guilford and Spearman-Brown (Bahri and Zamzam, 2014). The reliability test results are presented in Table 4.

Instrument	Cronbach's Alpha	*N* of Items
Spatial reasoning abilities	0.622	30
Mathematics anxiety	0.642	12
Spatial anxiety	0.506	6

Table 4: Output Reliability Test of the Three Instruments

Table 4 displays Cronbach's alpha coefficients of 0.622 for spatial reasoning and 0.642 for mathematics anxiety, indicating acceptable internal consistency. However, the Spatial Anxiety Instrument did not perform as well. After removing problematic items, the revised instrument achieved a Cronbach's Alpha coefficient of 0.506. Although below the acceptable threshold, considering the time constraints, the exploratory and local nature of the research context, and the content validity that has undergone expert validation, the instrument was still used with certain limitations. The researcher suggests that this instrument be refined in future studies. The analysis was conducted using descriptive statistics to identify the trends in the data for the three variables and was also categorized by gender and grade level. Mediation and moderation analysis were employed to address the primary questions. All analyses are conducted using the SPSS software application.

RESULTS

Descriptive Data

Descriptive data and correlation analysis between variables and dimensions are presented in Table 5.

Table 5 presents the mean scores and standard deviations for each component of spatial reasoning abilities, along with the correlation coefficients between each component and spatial reasoning. Spatial orientation has the highest mean score of 6.338 (SD = 1.992), indicating participants performed well in tasks related to spatial orientation. The coefficient score of 0.796 indicates that spatial orientation has the strongest impact on overall spatial reasoning performance. Spatial visualization has the lowest mean score of 2.931 (SD = 1.517), suggesting participants performed less effectively in tasks related to spatial visualization. Spatial visualization has the least influence on spatial reasoning, with an influence coefficient of 0.668.

Table 5 shows that spatial reasoning and its components have a negative effect on mathematics anxiety and spatial anxiety. Spatial reasoning has a negative correlation with both anxiety and mathematics anxiety, with a coefficient of -0.092, and spatial anxiety, with a coefficient of -0.194. Higher levels of mathematics anxiety are associated with lower levels of mental rotation, but their influence on another component of spatial reasoning is not significant. Spatial anxiety has a more pronounced negative impact on spatial orientation than spatial visualization and mental rotation.

Based on Table 5, except for mental rotation, grade level appears to have a significant relationship with spatial reasoning and its components. Meanwhile, gender is found to have a significant relationship with spatial reasoning and its components, except for spatial visualization. Both grade level and gender are significantly correlated with mathematics anxiety. However, spatial anxiety does not show a significant relationship with these variables. Table 6 and Table 7 show, respectively, the analysis of the two variables, grade level and gender, on spatial reasoning, mathematics anxiety, and spatial anxiety.

Variable	Mean	SD	Min	Max	SR	SOR	SV	MR	MA	SA	Grade	Gender
SR	12.352	3.797	4	24	—							
SOR	6.338	1.922	1	10	0.796***	—						
SV	2.931	1.517	0	8	0.668***	0.300***	—					
MR	3.088	1.681	0	9	0.744***	0.384***	0.266***	—				
MA	23.000	5.605	12	40	-0.092*	-0.064	-0.020	-0.111*	—			
SA	10.774	3.153	6	24	-0.194***	-0.194***	-0.104*	-0.122**	0.220***	—		
Grade	—	—	—	—	0.232***	0.299***	0.120**	0.076	0.279***	-0.080	—	
Gender	—	—	—	—	0.145**	0.173***	-0.006	0.131**	-0.138**	-0.063	-0.119**	—

** p <.1, ** p <.05, *** p <.01*

Note: SR = Spatial Reasoning; SOR = Spatial Orientation; SV = Spatial Visualization; MR = Mental Rotation; MA = Mathematics Anxiety; SA = Spatial Anxiety

Table 5: Descriptive Data and Correlation Among Variables

	Gender	*N*	Mean	SD	Min	Max	*t*(475)	*p*	*d*
Spatial Reasoning	Female	232	11.789	3.499	4	23	-3.184	0.002	-0.292
	Male	245	12.886	3.993	4	24			
Mathematics Anxiety	Female	232	23.793	5.383	12	40	3.033	0.003	0.278
	Male	245	22.249	5.717	12	40			
Spatial Anxiety	Female	232	10.978	3.010	6	23	1.382	0.168	0.127
	Male	245	10.580	3.277	6	24			

Table 6: Analysis of Gender and Spatial Reasoning, Mathematics Anxiety, and Spatial Anxiety

Table 6 shows that male students have a higher mean spatial reasoning score than female students. The mean score for male students was 12.886, which was higher than the mean score for female students, which was 11.789. In terms of mathematics anxiety, female students have a higher mean score of 23.793 compared to males at 22.249. On average, female students report higher levels of mathematics anxiety. In terms of spatial anxiety, both male and female students have higher mean scores, with male students scoring 10.978 and females scoring 10.580.

	Spatial Reasoning			Mathematics Anxiety			Spatial Anxiety		
	4th-grade	5th-grade	6th-grade	4th-grade	5th-grade	6th-grade	4th-grade	5th-grade	6th-grade
N	185	179	113	185	179	113	185	179	113
M	11.362	12.575	13.619	21.470	22.933	25.611	11.011	10.804	10.336
SD	3.485	3.644	4.111	5.462	5.728	4.649	3.328	3.215	2.708
Min	4.000	5.000	5.000	12.000	12.000	14.000	10.000	10.000	10.000
Max	24.000	23.000	24.000	37.000	40.000	40.000	29.000	28.000	28.000
F	13.572, $p < .001$			20.750, $p < 0.001$			1.623, $p = 0.198$		

Table 7: Analysis of Grade Level and Spatial Reasoning, Mathematics Anxiety, and Spatial Anxiety

Table 7 presents the differences in mean values for mathematics anxiety, spatial anxiety, and spatial reasoning ability across various grade levels. Mathematics anxiety increases sequentially from grade 4 to grade 6, suggesting that higher grade levels tend to have higher mean scores. On the other hand, spatial anxiety has the highest mean score for grade 4 students, followed by grade 5, and the lowest mean score for grade 6. Grade 4 students generally exhibit higher levels of spatial anxiety compared to students in grades 5 and 6. Additionally, spatial reasoning ability has the highest mean score among grade 6 students, followed by grade 5, and the lowest among grade 4. This suggests that as students advance to higher grade levels, their spatial reasoning abilities tend to improve.

Mediation Analysis

We perform mediation analysis using the PROCESS feature in SPSS to evaluate the direct and indirect effects of mathematics anxiety on spatial reasoning, considering the mediating role of spatial anxiety. Additionally, it allows for examining the effects of grade level and gender on spatial anxiety and spatial reasoning. A summary of the analysis results is shown in Table 8.

Based on Table 8, the regression model describes a significant variance in both spatial anxiety ($R = 0.269$, $F(3, 473) = 12.251$, $p < 0.001$) and spatial reasoning ($R = 0.324$, $F(4, 472) = 18.521$, $p < 0.001$). This model examines the role of spatial anxiety as a mediator in the relationship between math anxiety and spatial reasoning. The measures and paths include:

1. Path from Math Anxiety to Spatial Anxiety
   As shown in the table above, math anxiety has a positive and significant effect on students' spatial anxiety with $b = 0.145$, $p < 0.001$.
2. Path from Spatial Anxiety to Spatial Reasoning
   Spatial anxiety (SA) has a direct negative and significant effect on spatial reasoning ($b = -0.165$, $p < 0.05$), indicating that higher levels of spatial anxiety are associated with lower spatial reasoning scores.

3. Path of Mathematical Anxiety and Spatial Reasoning
   In the direct effect, mathematical anxiety has a significant negative direct effect on spatial reasoning (b = -0.103, $p < 0.001$), indicating that higher levels of mathematical anxiety are associated with lower spatial reasoning scores.
4. Path of indirect effect
   As shown in Table 8, the evidence supports the hypothesis that spatial anxiety mediates the relationship between math anxiety and spatial reasoning. The indirect effect, which represents the mediating effect, is significant because the bootstrap confidence intervals do not include zero (Boot LLCI = -0.043, Boot ULCI = -0.007). This indicates that the relationship between math anxiety and spatial reasoning is partially mediated by spatial anxiety.

Table 8 also indicates the effects of covariates on spatial anxiety and spatial reasoning. Gender has a significant positive effect on spatial reasoning (b = 1.203, $p < 0.05$). However, there is no evidence that gender influences spatial anxiety levels. Grade level has a positive and significant effect on spatial reasoning (b = 1.436, $p < 0.05$). However, grade level has a negative effect on spatial anxiety (b = -0.639, $p < 0.05$).

	Coeff	SE	*t*	*p*			
Outcome: SA							
Constant	8.138	0.631	12.894	0.00			
MA	0.145	0.026	5.545	0.000			
Grade	-0.639	0.188	-3.400	0.001			
Gender	-0.293	0.283	-1.038	0.300			
Summary: SA	*R*	*R-sq*	*MSE*	*F*	*Df1*	*Df2*	*p*
	0.269	0.072	9.282	12.251	3.000	473.000	0.000
Outcome: SR							
Constant	14.221	0.860	16.532	0.000			
MA	-0.079	0.032	-2.500	0.013			
SA	-0.165	0.054	-3.058	0.002			
Grade	1.331	0.223	5.967	0.000			
Gender	1,155	0.332	3.480	0.001			
Summary: SR	*R*	*R-sq*	*MSE*	*F*	*Df1*	*Df2*	*p*
	0.350	0.123	12.984	16.473	4.000	472.000	0.000
Outcome: SR							
Constant	12.880	0.746	17.254	0.000			
MA	-0.103	0.031	-3.331	0.001			
Grade	1.436	0.222	6.461	0.000			
Gender	1.203	0.334	3.598	0.000			
Summary: SR	*R*	*R-sq*	*MSE*	*F*	*Df1*	*Df2*	*p*
	0.324	0.105	12.984	18.521	3.000	473.000	0.000

Note: SR =Spatial Reasoning; SOR = Spatial Orientation; SV = Spatial Visualization; MR = Mental Rotation; MA = Mathematics Anxiety; SA = Spatial Anxiety

Table 8: Summary of Mediation Analysis Results

Moderation Analysis

The role of moderator of spatial anxiety in the influence of mathematics anxiety on spatial reasoning is examined through a moderation analysis using the PROCESS feature in SPSS. The summary of the analysis is presented in Table 9.

Based on the information provided in Table 9, the results show that the effect of mathematics anxiety on spatial reasoning differs across different levels of spatial anxiety. In the low spatial anxiety group, the effect is statistically significant (b = -0.147; $p < 0.001$), suggesting that higher levels of mathematics anxiety are associated with lower spatial reasoning scores. In the medium spatial anxiety group, higher levels of mathematics anxiety are also associated with lower spatial reasoning scores, but to a lesser extent compared to the low anxiety group. In the high spatial anxiety group, the effect is not statistically significant (b = -0.012; p = 0.782), suggesting that there is no significant relationship between mathematics anxiety and spatial reasoning. These results indicate that the relationship between mathematics anxiety and spatial reasoning may vary depending on the levels of spatial anxiety. The impact of mathematics anxiety on spatial reasoning may be stronger when spatial anxiety is low or moderate, but becomes non-significant when it is high.

Group	SA	Effect	SE	*t*	*p*
Low	7.621	-0.147	0.042	-3.496	0.001
Medium	10.774	-0.079	0.031	-2.520	0.012
High	13.926	-0.012	0.042	-0.277	0.782

Table 9: Conditional effects of Mathematics Anxiety on Spatial Reasoning at Different Levels of Spatial Anxiety

DISCUSSION

This study aims to examine the relationship between mathematics anxiety, spatial anxiety, and spatial reasoning. We have formulated three hypotheses to explore these connections. Our first hypothesis suggests that math anxiety plays a significant role in determining spatial reasoning. Our second hypothesis proposes that spatial anxiety acts as a mediator between math anxiety and spatial reasoning. Finally, our third hypothesis suggests that the level of spatial anxiety conditions the relationship between math anxiety and spatial reasoning. Overall, our data support all three hypotheses.

First one, the results of the analysis indicate that the first hypothesis is not rejected, showing that mathematics anxiety significantly influences spatial reasoning with a direct negative effect. This means that the higher the mathematics anxiety, the lower the spatial reasoning ability. These findings align with a previous study by Ferguson et al. (2015), which reported that individuals experiencing mathematics anxiety also suffer negative consequences on their spatial reasoning. This phenomenon occurs because high mathematics anxiety can lead to difficulties in sensory control. Additionally, Wang (2020) corroborated these results, stating that mathematics anxiety negatively impacts spatial reasoning, which consequently affects the capacity to visualize and recall information during learning.

Second, the findings from our study support the second hypothesis, which suggests that spatial anxiety acts as a mediator in the relationship between mathematics anxiety and spatial reasoning. Our study indicated that higher levels of mathematics anxiety are associated with increased spatial anxiety, and in turn, elevated spatial anxiety is linked to lower spatial reasoning abilities. This implies that individuals with greater math anxiety are more likely to experience heightened levels of spatial anxiety, which, in turn, negatively affects their spatial reasoning skills. These results underscore the importance of addressing both mathematics and spatial anxiety to help individuals develop effective spatial reasoning abilities. A study by Ferguson et al. (2015) also reinforces these results, as it found that high math anxiety is associated with impaired sense of direction, spatial and general anxiety, and poorer performance on spatial reasoning tests. Furthermore, these findings remained consistent across tests conducted while considering gender and grade level variables, as well as when assessing the influence of the anxiety variable on spatial reasoning abilities.

Third, our findings reveal that the relationship between math anxiety and spatial reasoning may vary depending on the level of spatial anxiety. The influence of mathematics anxiety on spatial reasoning is more pronounced when spatial anxiety is low or moderate, but it becomes non-significant when spatial anxiety is high. In simpler terms, the effect of students' math anxiety on their proportional reasoning abilities is more significant when they belong to the lower spatial anxiety group. On the other hand, for students with higher spatial anxiety, the influence of mathematics anxiety on spatial reasoning is weaker. This is reasonable because spatial anxiety has a more substantial impact on spatial reasoning than mathematics anxiety. This conclusion is further supported by the correlation results, which indicate a stronger relationship between spatial anxiety and spatial reasoning than between mathematics anxiety and spatial reasoning, as shown in Table 5. These findings emphasize the crucial role of spatial anxiety in determining the relationship between mathematics anxiety and spatial reasoning. Therefore, addressing and reducing mathematics anxiety first could be a vital factor in mitigating the negative impact of spatial anxiety on proportional reasoning skills. Previous studies have also found that spatial anxiety is related to mathematics anxiety, and those with lower spatial reasoning have higher math anxiety (Douglas and LeFevre, 2018; Ferguson et al., 2015; Maloney and Beilock, 2012).

The descriptive statistics of this study also show that, in terms of gender, spatial reasoning ability is inversely proportional to the average math and spatial anxiety scores. Female students suffer more anxiety than male students in these two variables, implying that female students have a higher potential to experience mathematical anxiety and spatial anxiety. The level of math anxiety is affected by gender (Szczygieł, 2020), where female math anxiety dominated the proportion (Devine et al., 2012). Furthermore, this study explains math anxiety, and the anxiety test results show that females suffer more arithmetic anxiety than males (Devine et al., 2012). Santrock (2011) states that the concept that focuses on the differences between males and females is the corpus callosum, a collection of fibers that connects the two hemispheres of the brain. Females have a larger corpus callosum than males, which may explain why they are more conscious of their own and others' emotions. As a result, the level of mathematics anxiety among female students is higher than that of male students.

In contrast to math anxiety and spatial anxiety, according to some studies (Sorby, 1999, 2009), males tend to have better spatial reasoning, while females are considered better in areas such as language skills, motor skills, and reaction time. This suggests that gender roles impact students' spatial reasoning abilities. These findings have implications for education, particularly mathematics education. Since female students are more susceptible to anxiety, which impacts spatial reasoning, teachers can use this information to inform the implementation of learning activities. The findings of Furner and Marinas (2016) and Iossi (2007) suggest that engaging, technology-based learning can foster math understanding while reducing math anxiety. Best practices in mathematics learning can be implemented, such as the use of manipulatives (concrete math) and psychological techniques like anxiety management,

desensitization, counseling, support groups, bibliotherapy, and discussions (Zemelman et al., 2015).
In terms of grade level, spatial reasoning abilities, as indicated by the descriptive statistical data in this study, can be attributed to the fact that grade 6 has the highest average and standard deviation levels of spatial reasoning abilities. In contrast, grade 4 has the lowest levels. This level of spatial reasoning ability is comparable to mathematics anxiety, where information is obtained that the higher the grade level, the higher the level of mathematics anxiety (Szczygieł, 2020). Previous research (Salthouse, 1987) relevant to the results of this analysis states that differences in age maturity affect spatial reasoning. This finding aligns with research by Wang et al. (2014), which suggests that age, in conjunction with grade level, significantly moderates spatial reasoning. Because the subjects of this study were elementary school students, it can be inferred that their spatial reasoning will develop more at each grade level. Low-grade 1, grade 2, and grade 3 will differ from high-grade 4, grade 5, and grade 6, which logically have experienced better cognitive development. Compared to grades 4 and 5, grade 6 is at the highest level of thinking. Piaget argues that spatial reasoning is an aspect of cognition that develops in line with cognitive development, namely, the concept of a child's spatial reasoning develops along with their growth (Šafhalter et al., 2016). Starting from the very simple, starting when the child is at a low level of thinking, namely sensory-motor, to the highest level, namely formal operations. Therefore, it is relevant to note that grade 6 achieves the highest level of spatial reasoning ability because, at that age, their cognitive thinking level is the highest between grades 4 and 5. Meanwhile, it is inversely proportional to mathematics anxiety that spatial anxiety shows a negative influence, where the higher the grade level, the lower the value of spatial anxiety.
Related to the existence of a negative influence between spatial reasoning components on students' anxiety, Diezmann's (2009) study offers solutions on how teachers can develop students' spatial reasoning and work towards spatial literacy for all students. First, ensure that the development of spatial skills and various spatial activities is embedded in the mathematics curriculum. Second, support students to develop their spatial vocabulary and provide opportunities for them to use this language. Third, cultivate the development of students' visual memory and spatial reasoning with special attention to the visualization of blurred views, the placement and orientation of shapes, and different points of view. Fourth, provide concrete examples of tasks before expecting students to visualize them and encourage them to relate the task to their previous experiences. Fifth, follow up on students' difficulties and mistakes, and provide practice assignments on each sub-component of the problem assignment. Finally, utilize 21st-century technology to provide opportunities for developing spatial literacy.
From the perspective of efficiency, reducing mathematics and spatial anxiety can streamline learning by minimizing wasted effort and improving the effectiveness of mathematics instruction. From the perspective of responsibility, educators and policymakers bear the obligation to recognize and address affective challenges to ensure equitable and accountable educational practices in mathematics learning. Furthermore, this research will not only enrich the academic literature but also make a tangible contribution to creating a more efficient, effective, and accountable educational ecosystem for all students. This research suggests that to establish an efficient and accountable education system, both emotional and cognitive factors must be addressed as an inseparable whole. The results of this study contribute to the focus of research fields in education and the sciences, as well as the application of operations research in evaluating education and science.

LIMITATIONS

Although this study provides valuable insights into the affective and cognitive relationship between mathematics anxiety, spatial anxiety, and spatial reasoning among Indonesian elementary students, several limitations must be acknowledged to contextualize the findings and guide future research. One limitation of this study lies in the relatively low internal consistency of the spatial anxiety instrument (Cronbach's α = 0.506). This may have been influenced by the limited number of items, the affective and context-dependent nature of anxiety, and possible differences in item interpretation among younger respondents. Further validation and refinement of items are recommended for future studies. While we adhered to local ethical norms, the absence of a formal ethics review board and the use of verbal consent may not fully align with international ethical standards. Future studies should formalize their ethical procedures and align with global research protocols that involve minors. Future research should aim to develop more culturally appropriate and psychometrically sound instruments to assess spatial anxiety in young learners. Experimental or intervention-based designs could also be conducted to examine whether reducing mathematics and spatial anxiety can enhance spatial reasoning performance. Additionally, exploring qualitative data (e.g., student interviews) may provide deeper insights into students' emotional experiences during mathematical and spatial tasks.
Besides that, the limitations of this study include its focus on fourth-, fifth-, and sixth-grade elementary school students. The findings may not be directly generalized to other age groups, such as middle school students, college students, or adults. The dynamics between anxiety and cognitive ability may change with cognitive development, educational experiences, and different social pressures at each age level. Despite its limitations, this study highlights important affective factors influencing spatial reasoning in early education. It provides a foundation for future research that aims to integrate cognitive and emotional perspectives in mathematics education.

CONCLUSION

This study aims to test and validate our three proposed hypotheses, and the data analyzed have supported all three hypotheses. Firstly, mathematics anxiety has a negative impact on spatial reasoning. Additionally, our study's data indicates that spatial anxiety acts as a mediator in the relationship between math anxiety and spatial reasoning. Higher levels of math anxiety lead to higher spatial anxiety, which, in turn, results in lower spatial reasoning abilities.

Furthermore, our findings empirically demonstrate that the relationship between math anxiety and spatial reasoning may vary depending on the level of spatial anxiety. Mathematics anxiety appears to have a stronger effect on spatial reasoning when spatial anxiety is low or moderate, but this effect becomes less significant when spatial anxiety is high. The descriptive statistical data in this study also showed that female students' spatial reasoning plays a greater role in determining math anxiety and spatial anxiety than that of male students. Meanwhile, in terms of grade level, the level of spatial reasoning ability is comparable to math anxiety, where information is obtained that the higher the grade level, the higher the level of math anxiety.

Considering the above findings, addressing both mathematics and spatial anxiety becomes crucial for intervention, with a focus on addressing mathematics anxiety as a priority. Interventions targeted at math anxiety should also consider individuals' levels of spatial anxiety, as it can influence how math anxiety affects spatial reasoning. By addressing both types of anxiety in interventions, we can effectively support individuals in enhancing their spatial reasoning. The results of this study can serve as a reference to highlight the importance of paying attention to students' math anxiety, as it is directly related to spatial reasoning. Especially, research on math anxiety and spatial reasoning was conducted in Indonesia, where spatial anxiety has a direct relationship to math anxiety and spatial reasoning. In broader terms, this research contributes to building a more efficient and accountable education system, where both cognitive and affective aspects are integrated into teaching practices, aligning with educators' responsibility to ensure fair and effective learning.

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