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The Journal on Efficiency and Responsibility in Education and Science publishes papers of the following categories: full research papers, short communications, review studies and book reviews (on invitation only).

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- SHORT COMMUNICATION
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Papers are published in English. A paper may comprise an empirical study using an acceptable research strategy, such as survey, case study, experiment, archival analysis, etc. It may contain a theoretical study aimed at advancing current theory or adapting theory to local conditions or it may arise from theoretical studies aimed at reviewing and/or synthesizing existing theory. Concepts and underlying principles should be emphasized, with enough background information to orient any reader who is not a specialist in the particular subject area.

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The paper. The paper is carefully formatted according to the template of the journal (see bellow). Special attention is paid to the exact application of the Harvard referencing convention to both continuous citations and list of references. If an electronic source has the DOI number assigned, also it will be provided in the list of references. Manuscripts are submitted via the editorial system in the DOC.

Research highlights. The core results, findings or conclusions of the paper are emphasized in 2-4 bullet points (max. 150 characters per bullet point including spaces). The highlights are submitted as a text into the submission form in the editorial system.

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Papers must be closely scrutinized for typographical and grammatical errors. If English is not author's first language then the paper should be proof-read by a native English-speaking person, preferably one with experience of writing for academic use. Spelling should follow the Oxford English Dictionary.
Tables, graphs and illustrations should be drawn using a suitable drawing package. Colour may be used. Place all diagrams and tables where you wish them to appear in the paper. Ensure your diagrams fit within the margins and are resizable without distortion.

Review procedure

Following Editorial recommendation, papers are submitted to a double-blind peer review process before publication. Commentary by reviewers will be summarized and sent by email to authors, who can choose to revise their papers in line with these remarks. Re-submitted papers should be accompanied by the description of the changes and other responses to reviewers' comments (see above), so that the desk-editor can easily see where changes have been made.

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In this fourth issue of 2025 (Vol. 18, No. 4), we present seven articles that advance ERIES Journal's mission of promoting efficiency and responsibility in education and science. the contributions highlight three recurring themes: the use of diagnostic and evidence-based tools to strengthen learning; the integration of ICT and collaborative methods to foster creativity and innovation; and the exploration of affective dimensions—such as equity, anxiety, and responsibility—that shape inclusive educational environments. Together, these studies exemplify rigorous approaches that inform practice and policy while enriching the global dialogue on educational efficiency.

The first article, *"School Belonging, Safety, and Equity: Predictors of Academic Achievement in Kosovo's Education System"*, by Albulene Grajcevci and Arif Shala, examines how perceptions of safety, equity, and belonging influence achievement among 703 fifth-grade students. Findings show that supportive, mastery-oriented teaching fosters stronger outcomes than performance-driven approaches, with gender differences evident. the study underscores the importance of equitable grading and inclusive climates in closing achievement gaps. It provides valuable insights into how classroom practices can be leveraged to strengthen efficiency and responsibility in Kosovo's education system.

The second article, *"Breaking Down Barriers: Teachers' Attitudes Towards Transitioning from Specialization to Integrated Science Education"*, by Thi-Ngoc-Trinh Nguyen, Thi-Thi Vu, and Hanh Dinh, explores teacher attitudes toward Integrated Science Education in Vietnam. Surveying 203 in-service teachers, the study finds broad support for ISE despite reform-related anxiety, with professional development quality—not demographics—emerging as the decisive factor. the authors call for sustainable training aligned with systemic reforms to ensure effective and equitable integration. Their findings highlight the responsibility of policymakers to align reforms with teacher preparation for lasting impact.

The third article, *"Development of the Four-Tier Diagnostic Test to Identify Student Misconceptions in the Static Fluids Chapter"*, by Himawan Putranta and Fahdah Afifah, addresses misconceptions in physics education. A validated four-tier diagnostic test applied to 91 students revealed persistent difficulties in hydrostatic pressure and surface tension. the study highlights the value of diagnostic tools in systematically identifying and addressing learning barriers. It demonstrates how structured assessment can improve efficiency in teaching and support better learning outcomes.

The fourth article, *"Utilizing ICT-Based Learning Resources to Enhance Creativity and Innovation for Pre-Service Students of Vocational Education"*, by Budi Tri Cahyono, Hilmawan Wibawanto, Taufiq Subhanul Qodr, Fatma Sukmawati, Relly Prihatin, and Mochamad Kamil Budiarto, investigates ICT integration in vocational teacher education. A quasi-experimental study with 178 participants showed significantly higher gains in creativity and innovation when multimedia and simulations were embedded in learning. the authors emphasize structured ICT training and institutional support to prepare adaptable educators for Industry 4.0. Their work illustrates how digital tools can transform vocational education into a more innovative and future-ready field.

The fifth article, *"Boosting Creative Thinking and Entrepreneurial Attitude in Manado High School Students: Applying Scrum with Ethnochemistry Context in Green Chemistry"*, by Alessandro Jeremi Manarisip, Sri Handayani, Eli Rohaeti, and Siti Marwati, applies the Scrum framework in an ethnochemistry context. Involving 110 students, the study found significant improvements in creative thinking and entrepreneurial attitudes, despite implementation challenges. the authors recommend broader application of Scrum to cultivate innovation in chemistry education. This research shows how culturally contextualized methods can foster both efficiency and responsibility in science learning.

The sixth article, *"Exploring the Effects of Explicit Science Process Skill Instructions on Primary School Pre-Service Science Teachers' Nature of Science Conception"*, by Gidele Gito, Solomn Sorsa, Samuel Assefa, and Deribe Workineh, examines how explicit Science Process Skill instruction shapes pre-service teachers' understanding of the Nature of Science. Using the 4C/ID model with 69 participants, the study improved conceptions of observation, tentativeness, creativity, and methodology, though laws versus theories and cultural influences showed limited change. the authors recommend diverse strategies to foster comprehensive NOS competence. Their findings reinforce the need for multifaceted approaches to teacher education that balance efficiency with inclusivity.

The seventh article, *"Artificial Intelligence Literacy and Anxiety Levels of Pre-Service Science Teachers:*

A Mixed Method Study", by Burcu Akbay, Özlem Karakoç Topal, and Ayberk Bostan Sarıoğlan, explores AI literacy and anxiety among 136 preservice teachers. Results show relatively high literacy and moderate anxiety, with no significant correlation between the two. the authors highlight the need for structured training to enhance AI literacy and reduce uncertainty, preparing teachers to engage confidently with emerging technologies. This study emphasizes the responsibility of teacher education programs to equip future educators for the digital age.

In closing, we extend our gratitude to all authors whose innovative research enriches 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.

We wish you a Merry Christmas and a Happy New Year 2026.

Sincerely

Martin Flégl
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CONTENT

Full research paper

SCHOOL BELONGING, SAFETY, AND EQUITY: PREDICTORS OF ACADEMIC ACHIEVEMENT IN KOSOVO'S EDUCATION SYSTEM

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ABSTRACT

This study examines whether widely documented links between students' perceptions of safety, equity, and belonging and their academic performance, commonly found in Western contexts, also hold in Kosovo. Drawing on data from 703 fifth-grade students across 30 classrooms, it compares public and private schools and explores how classroom climate relates to achievement. Public school students reported higher levels of safety, equity, discipline, and connectedness than their peers in private schools, whose grades appeared substantially inflated and clustered at the top. In contrast, public schools displayed a broader and more differentiated distribution of achievement. Teacher practices emerged as a key factor: students performed better when teachers were perceived as placing less emphasis on performance goals, indicating that supportive, mastery-oriented classroom environments foster stronger learning outcomes. Multilevel analyses further showed that GPA and CoreGPA were shaped by distinct predictors, with connectedness and discipline playing different roles. Gender differences also appeared: among girls, equity and teacher performance goals were positively associated with achievement, whereas boys' outcomes were more strongly linked to connectedness. Overall, the findings highlight the importance of reducing performance-goal pressure, strengthening student-teacher relationships, and ensuring equitable environments and transparent grading practices to help narrow achievement gaps.

KEYWORDS

Efficiency in education, learning outcomes, school belonging, student safety, responsibility in education

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Highlights

- *Public school students reported higher safety, equity, discipline, and school connectedness than students in private schools.*
- *Teachers' adopted performance goals are detrimental to achievement. Students achieved more when they perceived teachers as using fewer performance goals, highlighting the negative impact of performance-oriented teaching.*
- *Grades of core cognitive courses make differences in achievement visible. Multilevel results show that equity, connectedness, and low teacher performance goals predict GPA and CoreGPA across genders.*
- *Data support the reconceptualization of discipline and learning in core cognitive courses. Core GPA was higher when discipline was rated lower, suggesting that students may equate discipline with strictness in cognitively demanding courses.*
- *Students´ feelings of belonging to the school shape how they perceive teacher practices in the classroom. School belonging influenced how students viewed teacher practices, which in turn shaped achievement through perceptions of teacher performance goals.*

INTRODUCTION

Education systems are increasingly evaluated not only by the outcomes they produce but also by how efficiently and responsibly they operate. Efficiency in education refers to the extent to which available resources (i.e., teachers, classrooms, curricula, and student time) are translated into learning outcomes and academic achievement (Hanushek & Woessmann, 2011). Responsibility, in contrast, emphasizes fairness, equity, and accountability within the system, ensuring that students have access to safe, supportive, and transparent learning environments regardless of their background (OECD, 2017a). Together, these concepts highlight the dual challenge facing education systems, particularly in developing contexts: maximizing learning with limited resources while ensuring schools uphold their duty to provide equitable and trustworthy educational opportunities.

Within this broader framework, constructs such as school belonging, safety, and equity emerge as central to both efficiency and responsibility. School belonging is commonly defined as the degree of acceptance, respect, and involvement students feel within an educational institution (Allen, 2025; Porter et al., 2021; Allen & Bowles, 2012; Allen et al., 2016). Students with stronger feelings of belonging report more engagement, higher self-esteem, optimism, and happiness, which are linked to more favorable learning outcomes (Anderman, 2002; Juvonen, 2006). Literature consistently demonstrates that belonging contributes to psychological well-being, security (Allen, 2025; Porter et al., 2021; Jethwani-Keyser, 2008), and improved academic performance (Jethwani-Keyser, 2008; Dukynaite & Dudaite, 2017), while also reducing antisocial behavior, depression, and substance use (Shochet et al., 2006; Catalano et al., 2004; Lee & Burkam, 2003; Schulenberg et al., 1994). Importantly, belonging is not uniformly distributed: it varies both between and within schools, often shaped by fairness, discipline, and teacher–student relationships (Ma, 2003; OECD, 2017a, 2017b). Teachers play a particularly influential role in shaping this sense of belonging. Supportive teacher-student relationships foster motivation, engagement, and resilience (Dukynaite & Dudaite, 2017; Durlak et al., 2011), while also serving as protective factors for disadvantaged learners (Chiu et al., 2016; Ma, 2003). Evidence from PISA demonstrates that students who perceive their teachers as caring and supportive report higher belonging and achieve better in mathematics (OECD, 2015). Conversely, students from immigrant or disadvantaged backgrounds often report unfair treatment, including insults from teachers, which is associated with diminished belonging (OECD, 2017a). Across contexts, students without supportive teachers are 1.6 times more likely to feel excluded from school (OECD, 2017b).

Building on this evidence, it becomes critical to assess whether these robust predictors of achievement identified in Western contexts, i.e., belonging, safety, and equity, also apply in developing education systems. In the case of Kosovo, no prior studies have systematically investigated these associations, leaving a gap in understanding whether interventions that strengthen efficiency and responsibility through supportive school climates can translate into higher student achievement. To that end, the present study aims to close this gap by providing scientific evidence to inform future educational interventions in Kosovo.

LITERATURE REVIEW

Why perceptions of school belonging are crucial to learning outcomes

There are many terms used to describe school belonging, and such terms include but are not limited to: belonging, attachment, engagement, and bonding (Allen, 2025; Porter et al., 2021; O'Brennan & Furlong, 2010; Barber & Schluterman, 2008; Brown & Evans, 2002; Libbey, 2004; Moody & Bearman, 2004). On close analysis, all these terms describe the same concept: the feeling that one belongs, is included, and is valued in an educational environment (Libbey, 2004; Moody & Bearman, 2004). This broad definition identifies three main pillars of the sense of belonging, namely: i.) school relationships and experiences; ii.) relationship with teachers; and iii.) students` feelings about the school (Allen et al., 2016). Pittman and Richmond (2007) argue that better-performing students will have a stronger sense of school belonging than other students. Other researchers reported that a higher sense of belonging impacted motivation not only in the short term but for 4 consecutive years (Gillen-O'Neel & Fuligni, 2013). Similarly, these students are also less likely to miss classes, drop out, or misbehave in school (Demanet & Van Houtte, 2012; Hallinan, 2008). An equally significant aspect of this debate is the reported link between self-efficacy beliefs and positive perceptions of learning (Lonczak et al., 2002). Likewise, students who felt that they belonged to a school were happier, had higher self-esteem (Jose et al., 2012; Law et al., 2013), and were less likely to exhibit antisocial behavior or substance abuse (Lonczak et al., 2002; Wilson & Lipsey, 2005). In addition, across academic settings, learners who have a good relationship with their teacher are better at using feedback to learn (Caprara et al, 2000; Cohen & Steele, 2002). Unfortunately, nowadays, with the variety of indicators and assessments, teachers are often teaching to meet these criteria rather than teaching students to learn, form relationships with them, or get to know who they teach. This can easily lead teachers to adopt negative perceptions of their job, which can further demoralize and fragment (Bradford & Braaten, 2018) and ultimately have a detrimental effect on students' perceptions of school belonging and, by extension, achievement.

The sense of belonging also incorporates the physical security provided by an environment that enables the person to work and engage with others (Radich, 2012). As such, the sense of belonging links not only to physical security but also to emotional security and overall comfort (Antonsich, 2010). "Belonging in school" refers to learners perceiving themselves to be "personally accepted, respected, included, and valued by others" (Goodenow, 1993, p. 80). Building on these definitions of school belonging, researchers maintain that the need for belonging is a basic motivation (MacDonald & Leary, 2005) and it generally links to positive outcomes (Walton & Cohen, 2007). In many countries around the world, interventions to improve schools are built around addressing children's needs for well-being and the prevention of negative antisocial behavior, such as bullying (Thapa et al., 2013; Turner et al., 2014). School climate refers to a wide range of school-based factors that influence learning, such as school-based relationships and interaction, values, and norms (McEvoy & Welker, 2000; Ramelow et al., 2015; Thapa et al., 2013; O'Malley et al., 2015; Turner et al., 2014). The main reason why, over the years, school climate has received growing interest among researchers and policy builders is the impact that the latter has in providing an environment in which students thrive and achieve higher (Hoy & Hannum, 1997; McEvoy & Welker, 2000; Ma & Klinger, 2000; Sherblom et al., 2006; Stewart, 2008). Addressing school climate may help reshape gender differences in learning motivation. Research on school performance generally indicates that girls often outperform boys (Novák et al., 2024; Eriksson et al., 2020), highlighting thus consistent gender-based differences in learning motivation (Coetzee et al., 2020; Silva-Arias et al., 2020).

Early research on educational achievement found that students' final grades were positively correlated with their relationships at school (Moos and Moos, 1978). After 26 years of research, Crosnoe et al. (2004) reported similar findings: stronger relationships between students and teachers were associated with higher grades. While there may be abundant literature in the Western educational research on the impact of school belonging as well as teacher-student relationships on achievement, in the case of Kosovo, there is a lack of understanding of whether these robust predictors of achievement can be generalized to the context of a developing country, a gap that present research aims to address. Understanding the extent to which schools and classrooms in general impact achievement by initially shaping student perceptions is important in the case of Kosovo, especially due not only to low achievement in large-scale assessments (Shala & Grajcevci, 2023; Shala et al., 2021) but also because the gap in achievement between groups of students is expanding at a rapid pace between assessment years. It expanded from a one-year gap in the PISA 2015 assessment to a 2.5-year gap in the PISA 2018 assessment, with students in private schools, and/or higher socioeconomic status, and/or residing in urban areas outperforming all other groups of students by a large margin (Shala & Grajcevci, 2023; Shala et al., 2021). At the same time, students' readiness for instruction, their preference for the subjects, and their confidence in their abilities were all linked to higher literacy levels (Grajcevci & Shala, 2024). To that end, understanding what impacts student achievement and, if we can, building on Western education literature to draft evidence-based interventions are the main challenges the present research aims to address.

The current study

According to Hopson and Lee (2011), supportive school climates can mitigate disadvantages among at-risk students, enabling them to perform at levels comparable to peers from more advantaged backgrounds. School climate has also been consistently linked to achievement in reading, science, writing, and mathematics (O'Malley et al., 2015). These findings consider both the efficiency and responsibility of schools as important to learning and achievement, i.e., efficiency in maximizing learning outcomes through social and emotional supports, and responsibility in ensuring equitable conditions that allow all students to thrive. Building on this literature, the present study examines how school belonging and students' perceptions of teacher practices shape achievement. School belonging was conceptualized through four constructs (whole-school connectedness, equity, safety, and discipline), while teacher practices, as perceived by students, were measured through three sub-constructs: teachers adopting performance goals, providing opportunities for group work, and fostering friendly, high-quality relationships.

The study was guided by the following research questions:

RQ1. To what extent do school context factors influence student achievement, and how does school belonging mediate this relationship?

RQ2. Are there gender and school-type differences in student perceptions of school belonging and teacher characteristics?

RQ3. To what extent do perceptions of school belonging and teacher practices predict achievement, and do these effects differ when comparing GPA with grades in core cognitive courses (mathematics, science, etc.)?

MATERIALS AND METHODS

To conduct this study, four master's students were trained in data collection procedures and research ethics. Schools were randomly selected from the four largest municipalities in Kosovo to ensure representation across diverse urban and educational settings. Within each participating school, two classrooms were randomly selected, yielding a final sample of 703 students from 30 classrooms. Paper-based questionnaires were administered in person by the trained research assistants. At the beginning of each classroom session, students were informed about the study's purpose, their rights as participants, and the voluntary nature of their participation. They were assured of anonymity and the right to withdraw at any point without consequence. Informed consent from parents or legal guardians was obtained in advance in collaboration with classroom teachers and school administrators.

Participants completed six demographic items covering gender, grade level, school type (public or private), GPA, grades on four key curriculum courses: Albanian Language, Mathematics, Man and Nature (exact science), and Society and Environment (social science), household income, and access to electronic learning resources. All procedures adhered to established ethical principles and guidelines for research involving minors. To minimize potential carryover effects, the survey included short pauses accompanied by clear transitions and neutral messaging (e.g., "Thank you for completing the previous section. Please take a moment before starting the next."). In addition, the order of the statements was randomized across participants to reduce the risk of systematic priming or framing effects associated with a fixed sequence. All questionnaire statements were administered in their original, validated form, with no modifications to item wording that might bias or prime participants' responses.

Participants

In the study population, 343 participants (48.8%) were female, 359 participants (51.1%) were male, and the remaining 0.1% did not identify with either gender. When asked about their mother's education, only 10 participants indicated that their mother had never attended school (1.4%), 101 participants (14.4%) indicated that their mother had completed elementary school, and a further 43 participants chose the option "Other" (6.1%) without giving any further information. Most participants indicated that their mothers had either a high school diploma (N = 261, 37.1%) or a bachelor's degree (N = 270, 38.4%). Similar data were collected for father's educational attainment, with participants reporting that their fathers predominantly had

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a high school diploma (N = 259, 36.8%), a bachelor's degree (N = 264, 37.6%), or some other educational qualification (N = 56) had.8%). Compared to the previous question, fewer respondents reported that their fathers had no education (N = 6, 0.6%) and that their fathers had completed elementary school (N = 88, 12.5%). Finally, 79.5% (N = 559) of the participants attended public schools, while the remaining 20.5% (N = 144) attended private schools.

	N	%		*N*	%
Gender			**Type of school attended**		
Female	343	48.8	Public	559	79.5
Male	359	51.1	Private	144	20.5
Mother's education level			**Father's education level**		
Never went to school	10	1.4	Never went to school	6	.9
Has completed primary school	101	14.4	Has completed primary school	88	12.5
Has completed secondary school	261	37.1	Has completed secondary school	259	36.8
Has completed university studies	270	38.4	Has completed university studies	264	37.6
Other	43	6.1	Other	56	8.0

Table 1: Descriptive statistics for the student sample.

Measurements

Teacher expectations

Perceptions regarding teachers adopting performance items from the PALS (Patterns of Adaptive Learning Scales) of Midgley et al. (2000). Sample items included: My teachers treat students who get good grades better than other students, & In my class, special privileges are given to students who get the highest grades. The Cronbach's α for the subscale of *perceived teacher performance goals* was .74 (answer choices ranging from 1-*completely disagree* to 4-*completely agree*).

Supportive practices

Teacher-supportive classroom practices were assessed using the SEEQ (Student Evaluation of Educational Quality) Questionnaire (Marsh, 1982). *Classroom group-work opportunities* were assessed with four items, and the Cronbach's *α* for this subscale was .71 (e.g., Students are encouraged to participate in class discussions, and students are invited to share their ideas and knowledge in groups). *Teachers' Quality and Friendly Relationships* with students were composed of two initial subscales: the *Teacher Support* subscale of the SEEQ Questionnaire and the *Relationship Quality* subscale of the PISA assessment cycle 2009. The alpha value of this subscale was .92 (i.e., Teachers are friendly towards students, Teachers make students feel welcome when asking for help/advice outside of class). In all cases, a four-point Likert Scale was used for the responses, ranging from 1 (*completely disagree*) to 4 (*completely agree*).

Safety

In the current research, school safety was measured with the Maryland Safe and Supportive School Climate Survey (Rezapour, Khanjani & Mirzaee, 2020). The *Safety* subscale had a Cronbach's *α* of.57 and consisted of the following two items: I feel safe at this school & I feel safe going to and from school. The *whole-school connectedness* subscale consisted of 4 items and had an *α* of .73 (i.e., I enjoy learning at this school & I like this school). The *discipline* subscale was composed of three items and had an α value of .82 (i.e., Students listen to the teachers & There are clear rules about student behavior). The *equity* subscale had a Cronbach's *α* of.77 and comprised 3 items (e.g., Everyone is perceived as equal in school). In all cases, a four-point Likert Scale was used for the responses, ranging from 1 (*completely disagree*) to 4 (*completely agree*).

Data analysis procedure

Data analyses were conducted in multiple stages. First, differences between groups were explored (i.e., t-tests, ANOVAs). Next, multilevel modeling was employed to account for the nested structure of the data, with students grouped within classrooms. This approach allowed us to examine both individual and classroom-level effects on achievement outcomes. Mediation analyses were also conducted to test the indirect effects of school belonging on the relationship between perceptions of teacher goal orientation and student achievement. Analyses were carried out using Mplus 8.0 and SPSS. Finally, statistical significance was determined at the $p < .05$ level. Graphs of the statistical tests conducted with Mplus were also generated automatically by Mplus.

RESULTS

Differences in perceptions based on school type, i.e., public vs. private educational institutions

The results of the *t*-tests reveal that students of public schools, compared to students attending private schools, held significantly higher perceptions about school safety ($M = 3.50$, $SD = .59$; $t(690) = 3.38$, $p < .001$), whole school connectedness ($M = 3.72$, $SD = .51$; $t(688) = 6.88$, $p < .001$), equity in school ($M = 3.55$, $SD = .63$; $t(689) = 6.20$, $p < .001$), discipline ($M = 3.59$, $SD = .48$; $t(690) = 4.79$, $p < .05$), teacher-friendly/quality relationships ($M = 3.59$, $SD = .48$; $t(701) = 3.92$, $p < .001$), teacher performance goals ($M = 2.12$, $SD = .95$; $t(685) = 2.42$, $p < .05$), and group interaction possibilities in the classroom ($M = 3.49$, $SD = .54$; $t(685) = 3.04$, $p < .05$).

Differences in grading based on the type of school

A Chi-Square goodness-of-fit test was performed to determine if the grading practices were similar between private and public schools. Results reveal significant differences in grading in Albanian Language classes, $\chi^2(3, 673) = 22.19$, p <.001, with private schools awarding higher grades than public schools. The same was true for grading in Math courses $\chi^2(3, 673) = 30.23$, $p < .001$, exact science courses $\chi^2(3, 672) = 31.41$, $p < .001$ and social science courses $\chi^2(3, 669) = 21.46$, $p < .001$, with only 0.8% of students receiving marks of 3 (good), between 9% and 10% received the grade 4 (very good) and the remaining 90% received the highest grade, 5. While no student in the private schools received a satisfactory mark of 2, this was not the case in public schools. In addition, there were significant differences in overall GPA, $\chi^2(3, 535) = 10.70$, $p = .005$, with 91% of students attending private schools receiving the highest GPA level (level 5, excellent), compared with only 76% of students in public schools. The data suggest that in private schools, grading is skewed toward very high grades; in public schools, grades are more evenly distributed across achievement levels. Based on these results, hypothesis 2 was supported.

Differences in perceptions based on GPA

ANOVA test results reveal that there are significant differences between groups in the perceptions of whole school connectedness $F(3, 699) = 5.00$, $p = .002$, equity $F(3, 699) = 3.46$, $p = .016$, teacher adopting performance goals $F(3, 699) = 8.51$, $p = .001$, and quality relationships with teachers $F(3, 699) = 4.12$, $p = .006$. Higher-performing students reported significantly lower perceptions of teachers adopting performance goals than other groups of students ($M = 1.88$, $SD = .89$). In other constructs, higher-performing students reported higher perceptions than all other students. Based on these results, the hypothesis was supported.

Differences in perceptions based on grades in specific courses

ANOVA results showed mixed patterns between achievement and perceptions. In Albanian language, significant differences appeared for discipline (F(4,696) = 2.71, p = .029) and teacher performance goals (F(4,696) = 9.53, $p < .001$), with top achievers reporting the lowest perceptions of teacher performance goals ($M = 1.89$, $SD = .88$), while average achievers reported the highest equity ($M = 3.47$, $SD = .67$). For Math, significant effects were found for connectedness ($F(4,698) = 3.18$, $p = .013$), equity ($F(4,698) = 2.94$, $p = .020$), discipline ($F(4,698) = 4.39$, $p = .002$), teacher performance goals ($F(4,698) = 9.12$, $p < .001$), and group interaction ($F(4,698) = 2.42$, $p = .047$). Here, top achievers again rated teacher performance goals lowest ($M = 1.88$, $SD = .89$), while average achievers reported higher perceptions across other scales. In exact sciences, differences emerged in connectedness ($F(4,698) = 3.66$, $p = .006$), discipline ($F(4,698) = 3.23$, $p = .012$), teacher performance goals (F(4,698) = 8.34, $p < .001$), and teacher relationships ($F(4,698) = 2.59$, $p = .036$); high achievers rated performance goals lowest ($M = 1.90$, $SD = .90$), while lowest achievers reported weaker discipline ($M = 3.28$, $SD = 1.12$). For social sciences, significant differences appeared for safety ($F(4,698) = 3.46$, $p = .008$), connectedness ($F(4,698) = 3.57$, $p = .007$), equity ($F(4,698) = 2.61$, $p = .034$), discipline ($F(4,698) = 5.00$, $p = .001$), teacher performance goals ($F(4,698) = 9.68$, $p < .001$), and teacher relationships ($F(4,698) = 2.98$, $p = .019$). Again, top achievers rated teacher performance goals lowest ($M = 1.90$, $SD = .89$), while average or lower achievers reported higher perceptions in most other areas. These findings suggest that high-achieving students are less receptive to performance-goal orientation, whereas average and lower achievers tend to report stronger feelings of belonging and support. This points to a potential misalignment between instructional emphasis on performance and the social-emotional needs of different achievement groups.

Multilevel analysis

Multilevel analysis of GPA and Core GPA

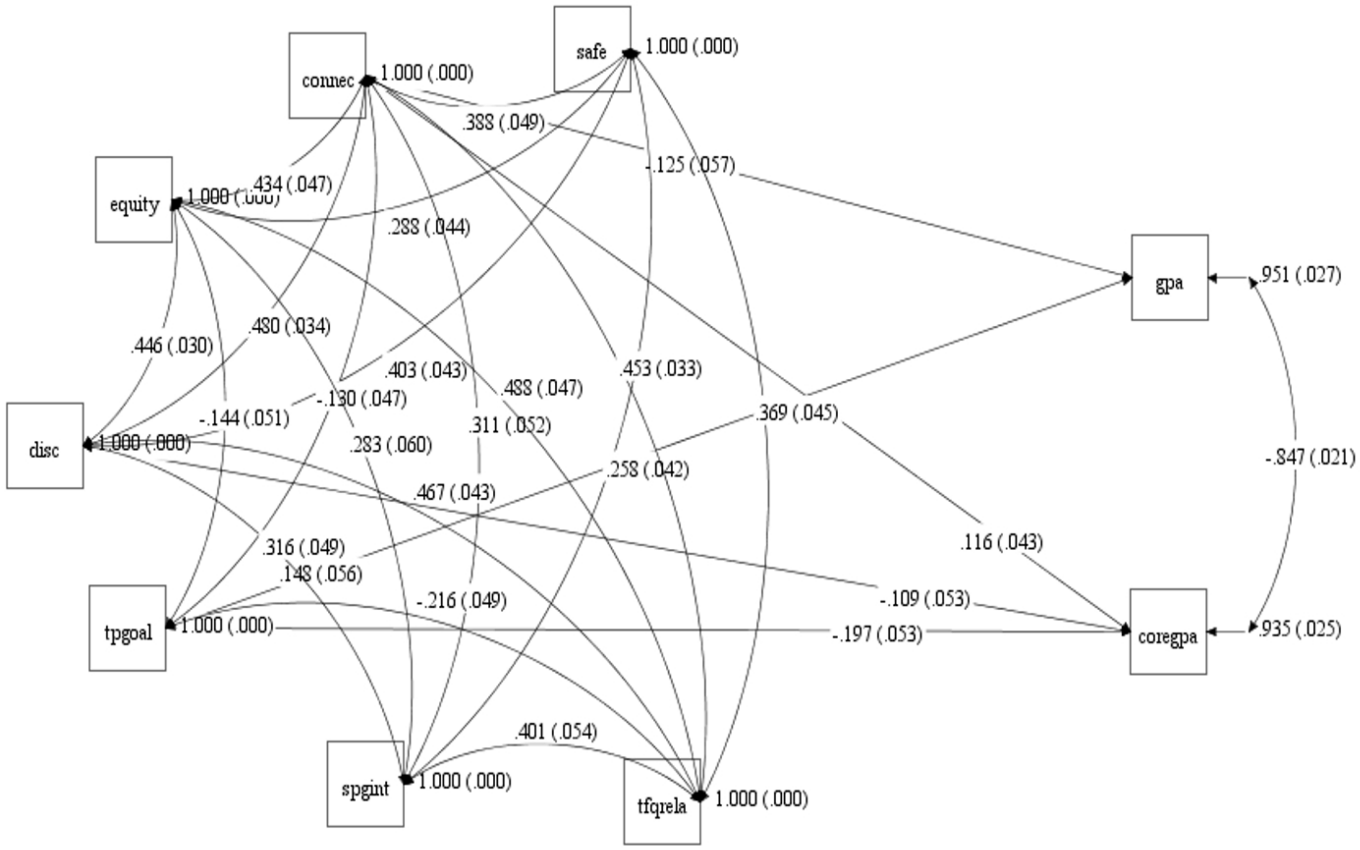
The working hypothesis of the present research was that higher levels of achievement would be associated with higher school belonging, higher levels of teacher-friendly and quality relationships, more opportunities for group work in classrooms, and lower levels of performance goals adopted by teachers.

The regression equation is:

$$Yk = \beta 0k + \beta 1k\text{SAFE} + \beta 2k\text{CONNEC} + \beta 3k\text{EQUITY} + \beta 4k\ \text{DISC} + \beta 5k\text{TPGOAL} + \beta 6k\text{SPGINT} + \beta 7k\text{TFQRELA} + \varepsilon k$$

Here Y_{GPA} = GPA and Y_{CoreGPA} = CoreGPA

To test this hypothesis, a multilevel analysis with classroom-level clustering was conducted (please see Figure 1 and Table 2 below). The chi-square for the model was significant, $\chi^2(15) = 515.53$, p = .001, and the alternative fit indices indicated a good fit to the data: CFI = 0.95 and SRMR = 0.09. Results of the multilevel analysis conducted with MPlus, clustered by classroom, indicate that GPA was predicted by feelings of being connected to school-Connec $\beta = -.125$, $p = .029$ and teachers adopting performance goals-TPGOAL $\beta = .148$, $p = .009$, with both variables accounting for 4.9% of the variance in GPA, but it was too low to be considered significant (p = -070). Core GPA was predicted by three variables: feelings of being connected to school (Connec; $\beta = .116$, $p = .008$), discipline (DISC; $\beta = -.109$, $p = .039$), and teachers adopting performance goals (TPGOAL; $\beta = -.197$, $p = .001$), accounting for 6.5% of the variance in achievement. This suggests that students will do better when their teachers do not adopt performance goals, especially when discipline is low, and students feel connected to the school. In addition, results report differences between measures of achievement: GPA is associated with two constructs (i.e., school connectivity & teacher performance goals), while CoreGPA is associated with three constructs (i.e., school connectivity, discipline & teacher performance goals). The difference lies in the CoreGPA construct, which is higher when discipline is lower.



Note: Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Figure 1: Multilevel analysis for GPA and CoreGPA and the study variables, at classroom level, for the study variables. Only significant parameters are represented by arrows. Std. coefficients presented.

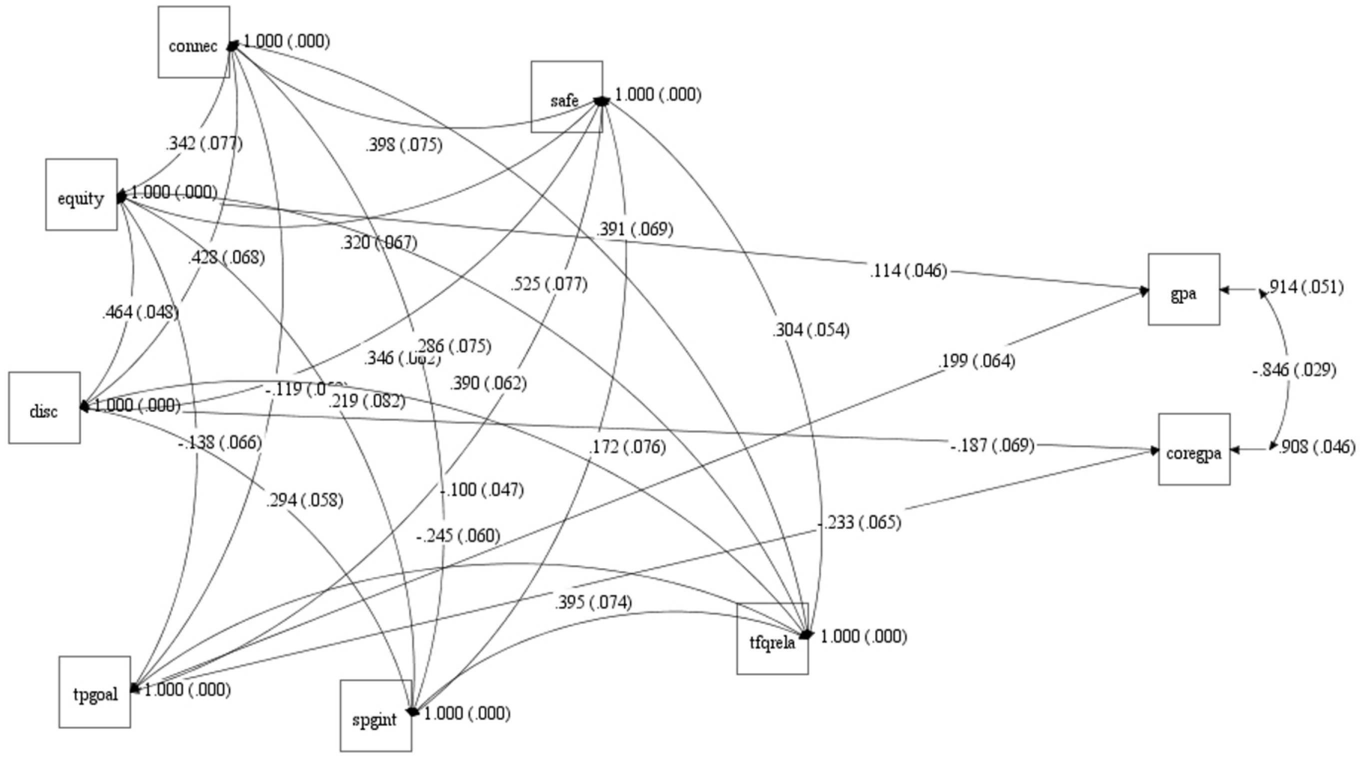
Variable	Std. Estimate	S.E.	*p*
SAFE → GPA	0.057	0.045	.203
CONNEC → GPA	-0.125	0.057	.029
EQUITY → GPA	0.066	0.047	.158
DISC → GPA	0.068	0.067	.311
TPGOAL → GPA	0.148	0.056	.009
SPGINT → GPA	-0.012	0.054	.823
TFQRELA → GPA	-0.090	0.063	.154
R-Square	**0.049**	**0.027**	**.070**
GPA unexplained variance	-		
SAFE → CoreGPA	-0.041	0.041	.321
CONNEC → CoreGPA	0.116	0.043	.008
EQUITY → CoreGPA	-0.039	0.053	.458
DISC → CoreGPA	-0.109	0.062	.039
TPGOAL → CoreGPA	-0.197	0.053	.001
SPGINT → CoreGPA	0.006	0.046	.902
TFQRELA → CoreGPA	0.069	0.061	.258
R-Square	**0.065**	**0.025**	**.009**
CoreGPA unexplained variance	**0.935**		

Note: Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Table 2: Parameter Estimates- Multilevel Analysis conducted with Mplus.

Multilevel analysis: Gender differences

The hypothesis of this study states that higher achievement among female students will be associated with higher school belonging, higher levels of teacher-friendly and high-quality relationships, more opportunities for group work in classrooms, and lower levels of performance goals adopted by teachers. To test this hypothesis, a multilevel analysis with classroom-level clustering was conducted (please see Figure 2 and Table 3 below). The chi-square for the model was significant, χ^2 (15) = 237.50, p = .001, and the alternative fit indices indicated a good fit to the data: CFI = 0.940 and SRMR = 0.08. Results of the multilevel analysis conducted with MPlus, clustered by school type, indicate that, for female students, GPA was significantly impacted by perceptions of school equity (EQUITY.114, p = .014) and by teachers adopting performance goals (TPGOAL β = .199, p = .002), accounting for 8.6% of the variance in achievement. This suggests that female students will do better in schools with greater equity and when teachers adopt performance goals. CoreGPA was impacted by perceptions of school discipline (DISC; β = -.187, p = .007) and by teachers adopting performance goals (TPGOAL; β = -.233, p = .001), accounting for 9.2% of the variance in grades. To that end, it suggests that female students will do better when there is less discipline and when teachers adopt performance goals.



Note: Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Figure 2: Multilevel analysis for GPA, CoreGPA, and the study variables, at the classroom level for female students. Only significant parameters are represented by arrows. Std. coefficients presented.

In addition, the chi-square for the model conducted on male students was significant, χ^2 (15) = 314.54, p = .001, and the alternative fit indices indicated a good fit to the data: CFI = 0.98 and SRMR = 0.07 (please see figure 3 and table 4 below). Results of the multilevel analysis conducted with MPlus, clustered by school type, indicate that GPA for male students was not predicted by any of the variables studied. However, CoreGPA was predicted by feelings of connection to school (Connec; β = .161, p = .009) and by teachers adopting performance goals (TPGOAL; β = -.161, p = .006), accounting for 5.4% of the variance in achievement. This suggests that students will do better when they have teachers who do not adopt performance goals and when they feel connected to the school, only in the case of CoreGPA; in the case of GPA, there was no association between variables. The hypothesis was partially supported.

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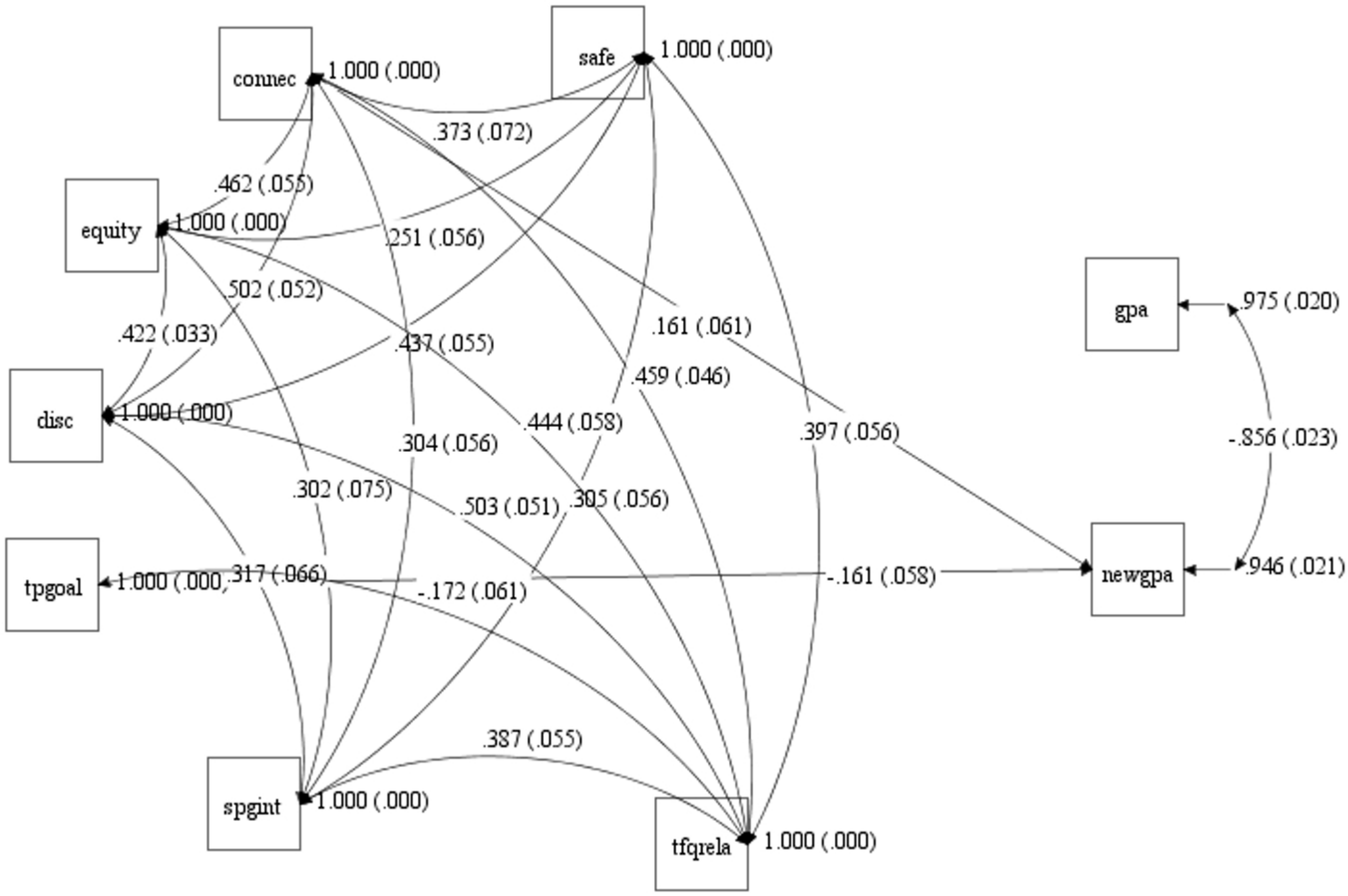
Variable	Std. Estimate	S.E.	*p*
SAFE → GPA	0.040	0.062	.515
CONNEC → GPA	-0.127	0.120	.292
EQUITY → GPA	0.114	0.046	.014
DISC → GPA	0.078	0.095	.414
TPGOAL → GPA	0.199	0.064	.002
SPGINT → GPA	-0.026	0.072	.719
TFQRELA → GPA	-0.141	0.072	.959
R-Square	**0.086**	**0.051**	**.008**
GPA unexplained variance	**.914**		
SAFE → CoreGPA	-0.007	0.078	.932
CONNEC → CoreGPA	0.048	0.080	.552
EQUITY → CoreGPA	-0.004	0.058	.949
DISC → CoreGPA	-0.187	0.069	.007
TPGOAL → CoreGPA	-0.233	0.065	.001
SPGINT → CoreGPA	0.038	0.073	.605
TFQRELA → CoreGPA	0.082	0.062	.189
R-Square	**0.092**	**0.051**	**.047**
CoreGPA unexplained variance	**0.908**		

Note: Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Table 3: Parameter Estimates- Multilevel Analysis conducted with Mplus.



Note. Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Figure 3: Multilevel analysis for GPA, CoreGPA, and the study variables, at the classroom level for male students. Only significant parameters are represented by arrows. Std. coefficients presented.

Variable	Std. Estimate	S.E.	*p*
SAFE → GPA	0.065	0.061	.288
CONNEC → GPA	-0.103	0.065	.110
EQUITY → GPA	0.045	0.058	.437
DISC → GPA	0.061	0.080	.449
TPGOAL → GPA	0.098	0.066	.136
SPGINT → GPA	0.002	0.069	.976
TFQRELA → GPA	-0.053	0.092	.565
R-Square	**0.025**	**0.020**	**.203**
GPA unexplained variance	-		
SAFE → CoreGPA	-0.075	0.046	.102
CONNEC → CoreGPA	0.161	0.061	.009
EQUITY → CoreGPA	-0.069	0.069	.319
DISC → CoreGPA	-0.035	0.066	.595
TPGOAL → CoreGPA	-0.161	0.058	.006
SPGINT → CoreGPA	-0.042	0.056	.452
TFQRELA → CoreGPA	0.039	0.075	.604
R-Square	**0.054**	**0.021**	**.011**
CoreGPA unexplained variance	**0.946**		

Note: Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Table 4: Parameter Estimates- Multilevel Analysis conducted with Mplus.

Overall, these findings highlight clear gender differences in the predictors of achievement. Female students' outcomes appear more sensitive to perceptions of equity, discipline, and teacher performance goals, while male students' achievement is mainly shaped by connectedness and reduced emphasis on performance goals, suggesting that interventions to improve achievement may need to be tailored differently for boys and girls.

Mediating effect of teacher and classroom practices in student achievement

The working hypothesis of this research study was that school belonging constructs will mediate perceptions of teacher practices, with the latter predicting achievement in both general GPA and CoreGPA. A multilevel analysis conducted with MPlus, clustered by school type, to test for mediation effects of school safety, equity, discipline, and connectedness to school on the perceptions of teacher performance goals, opportunities for group work, and teachers being friendly to students, with the latter variables then predicting student achievement (i.e., GPA and Core GPA).

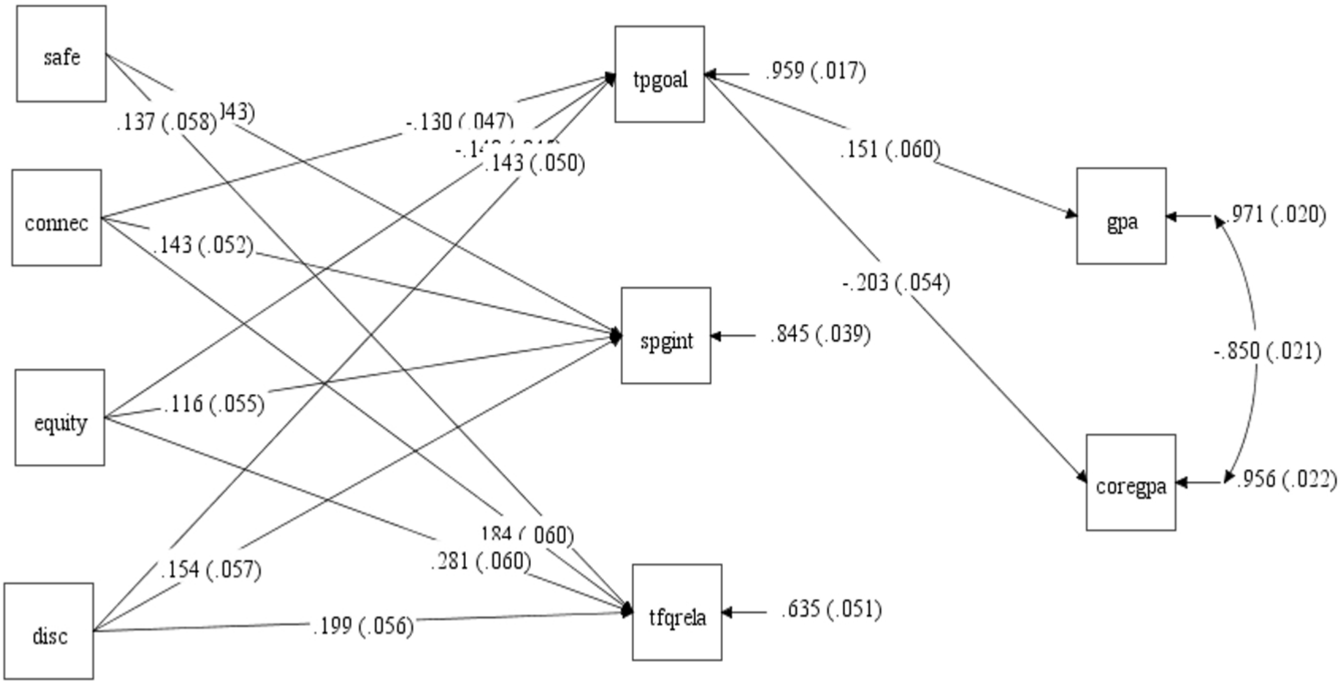
The regression equations were specified as follows:

$$Y = (\delta + \Lambda\alpha) + \Lambda\Gamma X + \Lambda\varepsilon m + \varepsilon$$

Γ contains all paths from (SAFE,CONNEC,EQUITY,DISC) to (TPGOAL,SPGINT,TFQRELA)

Λ contains all paths from (TPGOAL,SPGINT,TFQRELA) to Y (GPA,CoreGPA)

The chi-square for the model was significant, χ^2 (11) = 52.279, p = .001, and the alternative fit indices indicated a good fit to the data: CFI = 0.94 and SRMR = 0.04 (please see Figure 4 and Table 5 below). Results of the analysis indicate that perceptions of teachers adopting performance goals (TPGOAL) were significantly impacted by feelings of being connected to school (Connec; β = -.130, p = .005), equity (EQUITY; β = -.148, p = .001), and school discipline (DISC; β = .143, p = .004), explaining 4% of the variance (p = .020). Suggesting that students report lower levels of performance goals when they feel connected to school, when discipline is low, and when they perceive the school to be equitable, and vice versa. The perceptions of teachers adopting performance goals (TPGOAL) then significantly predicted achievement, β = .151, p = .012, accounting for 3.2% of the variance in GPA. The same was evident in the case of CoreGPA: β = -.203, p = .001, accounting for 5.1% of the variance in CoreGPA grades. The results in both cases suggest that when students perceived that teachers did not adopt performance goals, they also did better in school. Other variables did not have any significant impact on student achievement.



Note: Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Figure 4: Multilevel analysis for GPA and CoreGPA, and the study variables representing the mediating effects of variables at the classroom level. Only significant parameters are represented by arrows. Std. coefficients presented.

Variable	Std. Estimate	S.E.	*p*
SAFE → TPGOAL	-0.018	0.034	.601
CONNEC → TPGOAL	-0.130	0.047	.005
EQUITY → TPGOAL	-0.148	0.045	.001
DISC → TPGOAL	0.143	0.050	.004
SAFE → SPGINT	0.110	0.043	.011
CONNEC → SPGINT	0.143	0.052	.006
EQUITY → SPGINT	0.116	0.055	.033
DISC → SPGINT	0.154	0.057	.006
SAFE → TFQRELA	0.137	0.058	.018
CONNEC → TFQRELA	0.184	0.060	.002
EQUITY → TFQRELA	0.281	0.060	.001
DISC → TFQRELA	0.199	0.056	.001
TPGOAL → GPA	0.151	0.060	.012
TPGOAL → CoreGPA	-0.203	0.052	.001
SPGINT → GPA	-0.009	0.052	.858
SPGINT → CoreGPA	-0.015	0.045	.735
TFQRELA → GPA	-0.062	0.056	.268
TFQRELA → CoreGPA	0.042	0.052	.415
R-Square (CoreGPA)	0.051	0.032	.009
R-Square (GPA)	0.032	0.062	.014

Note: Safe-School safety, Connec-connectivity to school, Equity, DISC-school discipline, TPGOAL-Teacher performance goals, SPGINT-Classroom group work opportunities, TFQRELA-Teacher-friendly and quality relationships.

Table 5: Parameter Estimates- Multilevel Analysis conducted with Mplus.

DISCUSSION

The present empirical analysis examined the association between school and classroom variables and student achievement, under the hypothesis that more favorable conditions would predict higher outcomes in both GPA and CoreGPA. Prior research has consistently shown that teacher characteristics (Rivkin, Hanushek, & Kain, 2005), peer influences (Hanushek et al., 2003), and class size (Hoxby, 2000) shape achievement. Students' perceptions of teachers are also central to learning outcomes (Sereda et al., 2024; Nabaho et al., 2017), with evidence suggesting that perceptions of teachers influence not only students' academic achievement but also how they perceive learning itself (Marksteiner et al., 2021; Shah et al., 2019).

Findings from this study indicate that students in public schools reported higher perceptions of equity, discipline, safety, and connectedness compared to their peers in private schools. Public schools' stronger performance in these areas may stem from donor-supported initiatives that prioritize equity and student well-being, as well as stricter teacher recruitment processes that ensure higher professional competence. By contrast, private schools, which are self-funded and often employ novice teachers on short-term contracts, appear less consistent in providing supportive learning climates. These differences highlight both efficiency, i.e., how effectively resources and practices are translated into positive student perceptions, as well as responsibility, i.e., how schools ensure equitable conditions across contexts. Notably, public schools benefit financially from donors through awareness-raising campaigns and resources, and, in many cases, these campaigns focus on equity and student well-being. This may have contributed to an improved overall school context.

Achievement outcomes further emphasize these dynamics. Students reported higher achievement when teachers adopted lower performance goals, suggesting that reducing performance pressure is an effective strategy for improving learning outcomes. Safety perceptions were also positively associated with achievement, consistent with evidence that safe and orderly schools attract more qualified teachers (DeAngelis & Presley, 2011) and foster stronger academic environments (Stronge, 2010). Yet, persistent issues such as bullying (Lunenburg, 2010; Woods & Wolke, 2003) and reliance on surveillance measures (Casella, 2010; Kupchik & Bracy, 2010) raise concerns about the responsibility of schools to ensure safety through inclusive policies rather than monitoring technologies, which may also reinforce stereotypes (Steeves, 2010). In Kosovo, widespread camera use in schools highlights this tension, calling for greater clarity on whether perceptions of safety are shaped more by surveillance or by genuine school policies.

Gender-based analyses revealed distinct predictors of achievement. For female students, GPA was positively associated with equity and negatively associated with teacher performance goals, while CoreGPA was associated with lower levels of discipline and performance goals. Male students' CoreGPA, by contrast, was associated with stronger school connectedness and reduced performance-goal orientation. These findings suggest that improving achievement requires tailoring interventions to different student groups, while responsibility entails recognizing and addressing the distinct needs of boys and girls.

A final contribution of this analysis lies in the mediating role of school belonging. Belonging variables shaped perceptions of teacher practices, which, in turn, influenced achievement, particularly by reducing the emphasis on performance goals. Teachers who overemphasize performance goals may inadvertently signal doubts about student capacity, undermining self-beliefs critical to achievement. This aligns with evidence that epistemological beliefs are strongly tied to motivation and effort (Hidayatullah & Csíkos, 2023) and that students who believe in their own abilities are more likely to persist and succeed in demanding tasks (Gijsbers et al., 2019).

Overall, the study emphasizes the importance of efficiency and responsibility in education. Efficiency is reflected in how teacher clarity, supportive climates, and student motivation enhance achievement without requiring additional resources. Responsibility emerges in ensuring fair grading, equitable environments, and accountability in both public and private schools. Strengthening both dimensions is crucial for reducing achievement gaps and creating a more effective and trustworthy education system.

CONCLUSION

The findings of this study highlight that both efficiency and responsibility are critical for understanding educational achievement in Kosovo. On the efficiency side, results demonstrate that clear instructional practices, teacher job satisfaction, and teaching experience significantly enhance student performance in mathematics and science. These factors illustrate how existing resources, when effectively deployed, can generate stronger outcomes without necessarily requiring additional financial investment. Similarly, student readiness, motivation, and subject preference proved to be efficient drivers of literacy, suggesting that policies aimed at strengthening learner agency and confidence can have substantial payoffs.

At the same time, issues of responsibility were evident across multiple results. Inflated grading in private schools undermines the credibility of assessment systems and creates inequities across school types, underscoring the need for stronger accountability mechanisms. The counterintuitive finding that students taught by teachers with secondary-level qualifications outperformed those taught by teachers with bachelor's degrees signals systemic inefficiencies in how qualifications and competencies are aligned and highlights policymakers' responsibility to improve professional standards and training. Multilevel analyses also revealed gender-based differences: female students' achievement was more sensitive to equity and discipline, while male students' performance depended more on connectedness and reduced performance-goal emphasis. These disparities point to schools' responsibility to create supportive and equitable environments tailored to diverse student needs.

Overall, the study suggests that improving Kosovo's education system requires a balance between efficiency, i.e., maximizing the impact of teacher practices and student dispositions on one hand, and responsibility, i.e., ensuring transparent grading, equitable access, and inclusive learning climates on the other. Strengthening both dimensions is essential to closing achievement gaps and building a more accountable, effective education system.

The present study has two limitations that should be considered when interpreting the findings. First, the measures of academic achievement relied exclusively on student self-reports of grades in specific courses and their general GPA, rather than on official school records. While self-reported grades are commonly used in research, they are not as reliable as assumed (Kuncel, Crede & Thomas, 2005), as self-reported values may be prone to recall errors, misreporting, or social desirability bias, which could have affected the results reported. Secondly, the questionnaire administered to participants was relatively long and may have contributed to survey fatigue. Extended surveys can reduce response quality, as participants may become less attentive or provide less accurate responses in the later sections. This may have been the case as the participants of this study were relatively young.

In conclusion, the findings of the present research suggest that school belonging, perceptions of equity, and teacher practices meaningfully shape academic achievement in Kosovo. Furthermore, findings imply that improving instructional clarity, reducing performance-goal pressures, and fostering supportive school climates could enhance achievement. Future research should examine how targeted interventions, i.e., innovative teaching approaches that both build on equity principles and foster a sense of belonging for students, can reduce achievement gaps and promote equity within Kosovo's education system.

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Full research paper

BREAKING DOWN BARRIERS: TEACHERS' ATTITUDES TOWARDS TRANSITIONING FROM SPECIALIZATION TO INTEGRATED SCIENCE EDUCATION

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ABSTRACT

Even though integrated science education (ISE) has been advocated globally for decades to enhance students' scientific literacy, developing countries with their own contextual conditions still face ongoing struggles in transitioning from subject specialization to integration. To ensure educational efficiency, specifically by reducing disciplinary fragmentation and optimizing resource use, understanding teachers' attitudes, along with diverse contextual factors, plays a pivotal role in the ISE movement. This quantitative study examines the attitudes of Vietnamese science teachers at various school levels, emphasizing differences in their attitudes across contextual variables, which informs strategies to enhance ISE promotion. The questionnaire-based methodology was employed to collect 203 responses, and the data were analyzed using one-way ANOVA. Our findings proved that (1) science teachers favored ISE despite the obstacles and anxiety of an educational reform; (2) traditional assumptions of contextual variables such as gender, years of teaching experience, and educational qualifications do not statistically differ in teachers' attitudes; (3) the quality of professional development might relate to teachers' perceived difficulty, anxiety, and self-efficacy towards ISE. Therefore, a sustainable, high-quality provision of professional development is essential to help teachers achieve ISE instructional objectives, alongside more practical solutions.

KEYWORDS

Contextual factors, educational efficiency, education reform, integrated science, integrated teaching, teachers' attitudes,

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Highlights

- *Despite constant struggles during the transition from subject specialization to integration, science teachers favored integrated science education (ISE).*
- *Traditional assumptions about contextual variables such as gender, years of teaching experience, and educational qualifications do not hold for teachers' attitudes.*
- *The quality of professional development is strongly associated with teachers' perceived difficulty, anxiety, and self-efficacy towards ISE, serving as a critical determinant of the educational efficiency of the ISE reformed curriculum.*

INTRODUCTION

Since the beginning of the 20th century, the United Nations Educational, Scientific, and Cultural Organization has widely advocated *integrated science education (ISE)* to deliver more meaningful educational experiences that improve students' conceptual understanding and the application of knowledge (Åström, 2008; Wei, 2020). Integration refers to the systematic organization of diverse subject matter into a cohesive framework that reflects how humans think and act; it involves designing educational programs that break traditional boundaries between fields of study, presenting them as a unified subject that focuses on innovation using modern tools and technologies and the applied process to solve complex problems (Åström, 2008; Bati, 2023; Kelley and Knowles, 2016). Transitioning from subject specialization to integration deems essential because it reflects the premise that science is a dynamic methodology for understanding natural phenomena and the crosscutting concepts in all science disciplines, such as seeking patterns in data, or cause and effect relationships, rather than a rigid collection of disparate subject-specific facts, hypotheses, and rules to be memorized and applied (Bastian and Fortner, 2018). To be more specific, unlike the subject-area specialization approach in science education, a transformative ISE encompasses (a) the integration of appropriate technology and engineering within the science and mathematics curriculum; (b) the promotion of scientific inquiry and engineering design, alongside rigorous mathematics and science instruction; (c) collaborative learning approaches that connect students and teachers across science fields and professionals; (d) the provision of global and multi-perspective viewpoints; and (e) the incorporation of strategies such as project-based learning, offering both formal and informal learning experiences to enhance learning (Kennedy and Odell, 2014).

The advantages and disadvantages of this transformation, however, remain contentious. On the one hand, specialization had a negative impact on school student achievement, especially in mathematics (Fryer, 2018). On the other hand, ISE has been claimed to provide students with a more cohesive grasp of complex real-world phenomena, enhancing not only their conceptual understanding but also 21st-century skills such as critical thinking and problem-solving, while boosting their engagement with school and interest in science subjects (Guerrero and Reiss, 2020; Kucuk, 2023; Li et al., 2020). Teachers' varied interpretations and approaches to integration are largely responsible for challenges associated with ISE implementation, including fluctuations in students' performance and motivation, increased teachers' workload, inefficiencies in infrastructure, and pedagogical, material, curricular and professional development limitations, concerns over inconsistent and unsubstantiated student assessments, teacher qualifications, and teacher shortages (Margot and Kettler, 2019; Pham et al., 2023; Thuan and Mau, 2021).

In these circumstances, science teachers and their attitudes towards ISE are playing a crucial role as primary catalysts for educational reforms because they are adopting ISE that goes beyond traditional science subjects, integrating innovative methods into science instruction, and simultaneously providing insights into resistance to change (Haatainen et al., 2021; Pillai et al., 2022; Strat et al., 2024). In 2023, Tytler et al. (2023) cautioned that disregarding teachers' attitudes and belief systems poses a significant risk to innovators' ability to sustain ISE deployment, as positive attitudes lead to success, while negative attitudes lead to failure and avoidance. Since then, little is known about teachers' attitudes, particularly those in developing countries and underrepresented groups striving to catch up with developed countries, and the contextual factors that shape them, such as gender, years of teaching, and professional development (Winarno, 2020). More importantly, recent reviews emphasize that contextual factors do not operate in isolation but interact with broader systemic influences, such as curriculum reforms, examination pressures, and the availability of instructional resources, to shape teachers' perceptions and practices (Shahali and Halim, 2024). Yet, few empirical studies have investigated these dynamics in developing countries, where the transition to ISE is particularly complex due to under-resourced school environments, limited teacher preparation, and top-down policy reforms (Pham et al., 2023; Vu, 2021). This lack of systematic evidence leaves unanswered questions about how contextual factors collectively relate to teachers' attitudes and whether certain factors are more dominant than others.

The case of Vietnam, a developing country, highlights this issue because its long-standing subject-specialized curriculum, combined with a high-stakes examination culture and chronic shortages of instructional resources, has made the transition to integrated science particularly challenging for teachers. In Vietnam, the 12-year national curriculum was originally structured to include physics, chemistry, and biology as separate subjects, delivered primarily through didactic lecturing. Beyond localized, small-scale projects, there was no experience with a comprehensive ISE. The high-stakes, examination-based educational system relies on assessing each subject in isolation. While this approach ensures a solid foundation in theoretical knowledge and technical accuracy, it can limit opportunities for hands-on experimentation, inquiry-based learning, and creativity in classroom practice. Moreover, many schools lack sufficient laboratory equipment, digital tools, and interdisciplinary teaching materials, making it difficult for teachers to design lessons that integrate science, technology, engineering, and mathematics in practical ways (Curtis, 2021). Until 2018, the Ministry of Education and Training introduced an integrative approach into the national curriculum to facilitate learners' comprehension of scientific principles, permit systematic problem-solving in an interdisciplinary manner, and promote informed decision-making, thereby promoting sustainable development of applied sciences and solving real-world problems (Bodewig et al., 2014; Doan, 2020).

However, Vietnamese science teachers seem to have expressed reluctance to adopt ISE, citing the primary cause of a lack of policy and training guidance during the transition and implementation of this approach across K-12 levels (Nguyen and Pham, 2021; Pham et al., 2023; Vu, 2021). Nguyen et al. (2020) argued that Vietnamese teachers' adoption of new integrated science instruction methods depends on understanding the various underlying contextual factors that influence their teaching behaviors, including years of experience, educational background, and the subjects they teach. Despite the initiation of ISE years earlier, Vietnamese students performed below the Organization for Economic Co-operation and Development average in the 2022 PISA science assessment. In order to remedy this problem, the Ministry of Education and Training (2023) temporarily experimented with co-teaching instruction, yet left in-service teachers without a vision for, or understanding of, how to develop high-quality, genuinely integrated lessons or curricula.

The current study seeks to address a significant gap in the body of research on educational contexts in developing countries, such as Vietnam, where limited attention has been given to the attitudinal responses of K–12 Vietnamese science teachers toward ISE. This focus is particularly critical given the absence of systematic investigations into their perspectives on both current practices and forthcoming trends during this pivotal transition to ISE. The research will also consider the contextual factors related to teachers' attitudes, alongside practical recommendations. The research questions are as follows:

RQ1:What are Vietnamese science teachers' attitudes toward teaching integrated science education (ISE)?

RQ2: What contextual factors shape Vietnamese science teachers' attitudes toward teaching integrated science education (ISE)?

LITERATURE REVIEW

Teachers' attitudes towards implementing integrated science education across K-12 levels

Science teachers' attitudes have been recognized as a key factor in determining the success of educational reform, shaping their ethical or unethical intentions and influencing their instructional practices in terms of frequency, quality, and content (Mâță et al., 2020). Attitudes are also claimed to guide teachers' actual classroom practices, including the acceptance of new approaches, techniques, and changes in their practices, often resulting from alterations in their attitudes (Thibaut et al., 2018). However, the definition or construct of "attitudes" varies across studies, as the term may refer to teachers' internal personal reinforcement, such as their emotional dispositions and cognitive perceptions (e.g., classified as good or bad), or to their external, dynamic, and reciprocal psychological interactions with students, encompassing perceived control and classroom management ideologies (e.g., positive or negative concepts underlying instructional behaviors) (Bandura, 1986).

Recent researchers (e.g., van Aalderen-Smeets et al., 2012; Thibaut et al., 2019; Pryor et al., 2016; Shidiq and Faikhamta, 2020) thus opted for a holistic definition that includes all the aforementioned constructs as complementary dimensions. Specifically, Pryor et al. (2016) explained that attitudes are shaped by the interplay between the perceived strength of intentions or beliefs about the likely outcomes of a behavior and the self-evaluation of those outcomes as they materialize, reflecting the actualization of those beliefs. They reported that high intenders had more favorable attitudes toward ISE and were likelier than low intenders to implement it. Likewise, Shidiq and Faikhamta (2020) stated that attitude is one of the personality aspects that can be influenced by the individual's internal feelings, such as cognition, knowledge, values, motivation, and self-efficacy, which refers to a person's belief in their ability to control these factors when translating them into real-world behavior.

Thibaut et al. (2018, 2019) conceptualized attitude more precisely through the Three-Component Model, which comprises three dimensions that predict and govern behavior: (1) the *cognitive component, referring to an individual's thoughts and opinions about the attitude object*; (2) the *affective component, involving the emotions or feelings associated with the attitude object*; and (3) the *perceived control component, reflecting the actions or responses of the individual when engaging with the attitude object*. Thibaut et al. (2018, 2019) indeed conducted a more detailed analysis of each dimension based on the work of van Aalderen-Smeets et al. (2012). They validated the subscales of teachers' attitudes toward teaching science. These subscales included two cognitive subscales, "perceived relevance" and "perceived difficulty" of teaching ISE, two subscales of teachers' affective states, "enjoyment" and "anxiety," and two subscales of perceived control, "self-efficacy" and "context dependency." Respectively, they defined the key terms as follows. Perceived relevance and perceived difficulty indicate the extent to which the community of science teachers considers ISE pertinent, practical, and challenging. Anxiety reflects the extent to which teachers experience stress, apprehension, or discomfort when teaching. High levels of anxiety may hinder a teacher's confidence and willingness to engage with ISE, thereby influencing their instructional behaviors and the overall success of ISE implementation. Self-efficacy refers to an individual's belief in their ability to successfully perform specific tasks or achieve desired outcomes in a given context. Thus, it encompasses teachers' confidence in mastering interdisciplinary content, applying innovative teaching methods, and managing classroom dynamics effectively. A high sense of self-efficacy empowers teachers to overcome challenges, adapt to diverse teaching contexts, and foster meaningful student engagement in ISE. Context dependency in the construct of attitudes refers to the extent to which teachers' attitudes are influenced by external contextual factors. These factors may include institutional policies, resource availability, support from colleagues or administrators, class size, curriculum design, or the socio-cultural environment in which teaching occurs.

The current study aligns with such a holistic definition of recent studies and employs the framework of attitudes developed by van Aalderen-Smeets et al. (2012), entailing the same dimensions. However, this study made a minor modification by excluding the "enjoyment" subscale. Although "enjoyment" is relevant, it is less critical to understanding actionable factors like perceived relevance, difficulty, anxiety, and self-efficacy, which directly yield explanatory power regarding teachers' resistance to change. Thibaut et al. (2017) also showed that "enjoyment" is strongly correlated with "self-efficacy" and thus provides less actionable insights compared to "anxiety."

Contextual factors related to teachers' attitudes toward integrated science education

Contextual factors have been influential in shaping teachers' attitudes, experiences, and adaptability to change, as well as their support and enthusiasm for schoolwide ISE initiatives (Mellati et al., 2015; Thibaut et al., 2019). Specifically, research found that teachers' gender, teaching experience, and education level are positively correlated with their attitudes (Al Salami et al., 2017; Margot and Kettler, 2019).

Specifically, female teachers have been found to have a more negative view of ISE education, specifically incorporating technology to implement it, than male teachers (Park et al., 2016). Although the incursion of women and girls into new technologies and science facilitates the elimination of the discrimination they have suffered, female teachers scored higher than their male colleagues on both the pretest and posttest in terms of their motivation to use Information and Communication Technology tools in ISE (Palomares-Ruiz et al., 2020). Still, while numerous studies have demonstrated significant disparities regarding attitudes between male and female teachers, others have observed minimal differences or even parallels in the general attitudes of both gender groups (e.g., Thibaut et al., 2019; Tweed, 2013).

The second component under consideration is teaching experience, typically measured by the number of years of professional experience. It is assumed that, over time, teachers accumulate mastery experiences, which contribute to enhanced self-efficacy, a component of attitudes (Bandura, 1986, 1997). Prior research has revealed a somewhat negative correlation between years of teaching experience and various aspects of teachers' perceptions of integrated STEM (Science, Technology, Engineering, and Mathematics) education (Thibaut et al., 2018, 2019). Especially given the limited number of role models who were experienced teachers with ISE, teachers in individual disciplines did not seem to have enough experience with integrated learning. In other words, while teachers may have spent years teaching their own subject matter, they had limited experiential knowledge and resources for envisioning what integrated science lessons should and could look like (Ryu et al., 2019).

Nonetheless, Kalliontzi (2022) reported no significant associations between demographic factors, such as gender and years of teaching experience, and teachers' beliefs or their implementation of integrated STEM practices. However, the study highlighted that certain characteristics, most notably higher levels of education (e.g., holding a master's degree) and specific age groups, were positively related to teachers' beliefs and their willingness to adopt an integrated approach. These findings suggest that while some commonly examined demographic variables may exert limited influence, advanced academic preparation and life-stage factors can play a meaningful role in shaping teachers' dispositions toward integrated STEM instruction.

Similarly, teachers' professional development is closely linked to their years of teaching experience. During the implementation of the education reform, professional development sessions are regarded as a fundamental tool for content delivery and must thus be understood. Literature indicates that the provision of professional development is positively connected with teachers' attitudes, improving teachers' self-efficacy beliefs regarding ISE, feeling less dependent on context factors, enjoying science teaching, and decreasing anxiety (Aldahmash et al., 2019; Dinh and Nguyen, 2023; Thibaut et al., 2019; van Aalderen-Smeets and Walma van der Molen, 2015) and can beneficially alter those previous negative viewpoints on ISE before the training (Al Salami et al., 2017; Nadelson et al., 2013). Professional development also greatly benefits science teachers to deploy ISE, as they may possess a positive attitude but often face challenges in understanding the concept of integration and its practical applications (Parmin et al., 2020). Even so, professional development has not consistently yielded the anticipated advantages for science teachers. Tweed (2013) conducted research revealing no substantial impact of professional development on teachers' self-efficacy.

Another characteristic is the teachers' educational backgrounds and qualifications. Teachers with varied academic backgrounds may display differing attitudes owing to ISE approaches. Prior studies reveal statistical differences in the perspectives of master's and undergraduate teachers regarding ISE (Clark et al., 2014). In contrast, Thibaut et al. (2019) examined this component; nevertheless, their results indicated no significant correlations between master's degrees and teachers' perceptions. In Vietnam, many teachers pursue master's degrees or higher qualifications due to salary incentives (Linh and Bell, 2024), so it would be advantageous to analyze the relationship between undergraduate and graduate programs and their role in shaping teachers' qualifications.

Lastly, research indicated a correlation between school/grade levels and teachers' psychological metrics, including attitudes. For instance, there exists a statistically negligible variation in teachers' opinions across various grade levels (Hackman et al., 2021), yet most research focuses on primary, secondary, and high schools' levels rather than higher education (Margot and Kettler, 2019), so minimal research elucidated the impact of this element on the overall attitudes of teachers, particularly in the domain of ISE.

The literature review establishes that determining the factors that shape attitude formation is crucial to the effective implementation of integrated science in educational reform. This study addresses this by examining both general attitudes toward integrated science and the impact of teachers' background characteristics and contextual factors. Altogether, Figure 1 illustrates the conceptual constructs of attitudes and five subscales related to three dimensions of attitudes, together with pertinent background or contextual factors influencing teachers' attitudes.

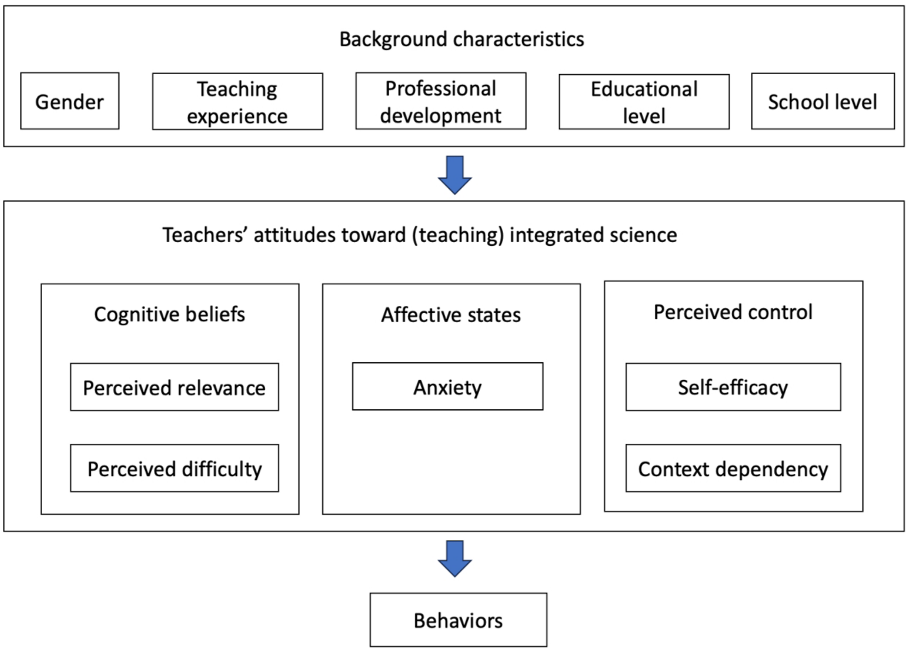

Figure 1: Theoretical Framework of Teachers' Attitudes toward ISE (Thibaut et al., 2018, 2019) and Background Factors

MATERIALS AND METHODS

Research design and sample

This study employed a questionnaire-based methodology to examine Vietnamese science teachers' attitudes toward Integrated Science Education (ISE) and to analyze demographic factors associated with their responses, thereby informing strategies for effective educational reform. According to Vaziri and Mohsenzadeh (2012), a questionnaire-based methodology enables the efficient collection of data from a large and diverse sample, allowing researchers to capture a broad range of perspectives, enhance reliability, and facilitate comparisons across different demographic groups. Additionally, closed-ended Likert-scale questions provide quantifiable data that can be analyzed statistically, yielding objective insights into complex phenomena. The anonymity they offer can encourage participants to respond more honestly, especially on sensitive issues such as their attitudes.

Table 1 delineates the demographics of the participating teachers. From May to November 2023, researchers gathered data from 203 in-service teachers teaching chemistry, biology, physics, and integrated (or natural) science at various educational levels. This sample demonstrates a broad and diverse representation across Vietnam, including gender, academic qualifications, teaching experience, school levels, and prior exposure to ISE.

A strong majority of participants were female (76.4%), reflecting the gender distribution of more female instructors, which is common in the teaching profession in Vietnam. Most teachers held bachelor's degrees, with a smaller proportion holding postgraduate qualifications, suggesting a range of academic preparation. Teaching experience was well distributed, with roughly one-third in their early career (less than 5 years), another third in the mid-range (5–10 years), and nearly 40% bringing more than a decade of experience, allowing insights from multiple career stages. In terms of teaching context, participants represented elementary, secondary, and high schools, as well as inter-level institutions, ensuring perspectives from across the education system. Notably, over one-third of the teachers had completed ISE training, making the sample particularly relevant for capturing both novice and trained viewpoints. Taken together, these characteristics suggest that the sample offers a meaningful and reasonably representative cross-section of Vietnamese science teachers, strengthening the reliability of the study's findings for informing educational reform.

Baseline characteristics	Full sample	Full sample
	n	%
Gender		
Male	48	23.6
Female	155	76.4
Teaching experience		
< 5 years	68	33.5
5-10 years	57	28.1
> 10 years	78	38.4
Professional development		
Not participating	69	34.0
Participated but not yet proficient	75	36.9
Participated and proficient	59	29.1
Education level		
Undergraduate degree	157	77.3
Postgraduate degree	46	22.7
School level		
Primary school	41	20.2
Secondary school	94	46.3
High school	43	21.2
Inter-level secondary school & high school	25	12.3

Table 1: the Distribution of Teachers by Gender, Educational Background, Teaching Experience, and Educational Level

The Instrument

The cross-sectional questionnaire in this study was adapted from the validated DAS instrument of van Aalderen-Smeets and Walma van der Molen (2013) and the aforementioned framework of primary teachers' attitudes toward science developed by van Aalderen-Smeets et al. (2012). Thus, the final instrument included 24 items of three dimensions as the cited theoretical framework of Figure 1 respectively, including (1) the cognitive beliefs: the relevance and importance of ISE (R) and perceived difficulty (D), and (2) the affective state including anxiety (A), and (3) perceived control including self-efficacy (S) and perceived dependence on contextual factors (C). Participating teachers were asked to respond to a five-point scale of attitudes toward teaching integrated science, ranging from "strongly disagree" to "strongly agree".

The changes and improvements made to the questionnaire language also took into account the four important aspects of teaching ISE (Åström, 2008): Combining different scientific fields, making the material relevant to everyday life, using student-centered teaching methods, and showing how science works. Therefore, the original instrument, DAS, underwent several modifications, necessitating validation and reliability testing of the final questionnaire. Initially, we conducted a content and face validity analysis. Three invited experts in science education expressed their approval and provided feedback on the translation process and the terminology used in the Vietnamese context. Secondly, we determined the Kaiser–Mayer–Olkin (KMO) and Bartlett's test of sphericity to verify the adequacy of the sample. The KMO test score was .884, showing that the factor analysis is appropriate. Bartlett's test of sphericity is statistically significant ($p < .001$), indicating that the observed variables are correlated within the factor. Finally, we evaluated the reliability of each dimension using Cronbach's alpha coefficient. All calculated alphas ranged from .829 to .935, indicating highly reliable scales (Nunnally, 1978).

Next, we conducted a confirmatory factor analysis (CFA) to assess the factor validity. According to Hu and Bentler (1999), the results indicate good fit when the CMIN/df value is less than 3, the RMSEA is less than 0.08, the CFI is greater than 0.9, and the TLI is greater than 0.9. Table 2's validation work established the developed instrument as a well-validated tool.

# of items	Cronbach's alpha	Construct validity			
		CMIN/DF	RMSEA	CFI	TLI
24	.887	2.270	0.079	.926	0.915

Table 2: Cronbach's Alpha Reliability and Construct Validity for Each Subscale of the Questionnaire.

Data analysis

This study employed AMOS 20 and SPSS 26 for quantitative analysis. For instrument development, Cronbach's alpha coefficients were calculated to assess the reliability of the research model. For validation work, the KMO value and Bartlett's test of sphericity were initially calculated to verify the sampling adequacy. CFA was used to test the appropriateness of the initially declared factor structure using model fit indices.

The first research question was answered by utilizing descriptive statistical analysis. The second one was addressed by evaluating the differences between subgroups. A one-way ANOVA was used to compare attitudinal scores across subgroups. Tukey's honestly significant difference test was calculated for post hoc comparisons. The eta-squared values were also calculated to examine the effect size of differences. Cohen (2013) classified eta-squared values based on the benchmark of small (0.01), medium (0.06), or large (0.14) effect.

RESULTS

RQ1. What are Vietnamese science teachers' attitudes toward teaching integrated science?

The mean of each dimension was examined to evaluate the overall teacher attitude toward integrated science teaching. Specifically, the mean values of *Perceived relevance* (*R*), *Perceived difficulty* (*D*), *Anxiety* (*A*), *Self-efficacy* (*S*), and *Context dependency* (*C*) are 3.89 ($SD = 0.97$), 3.25 ($SD = 1.04$), 2.96 ($SD = 1.06$), 3.41 ($SD = 0.95$), and 3.95 ($SD = 0.90$) respectively. Their distributions were illustrated in the following box plots (see Figure 2).

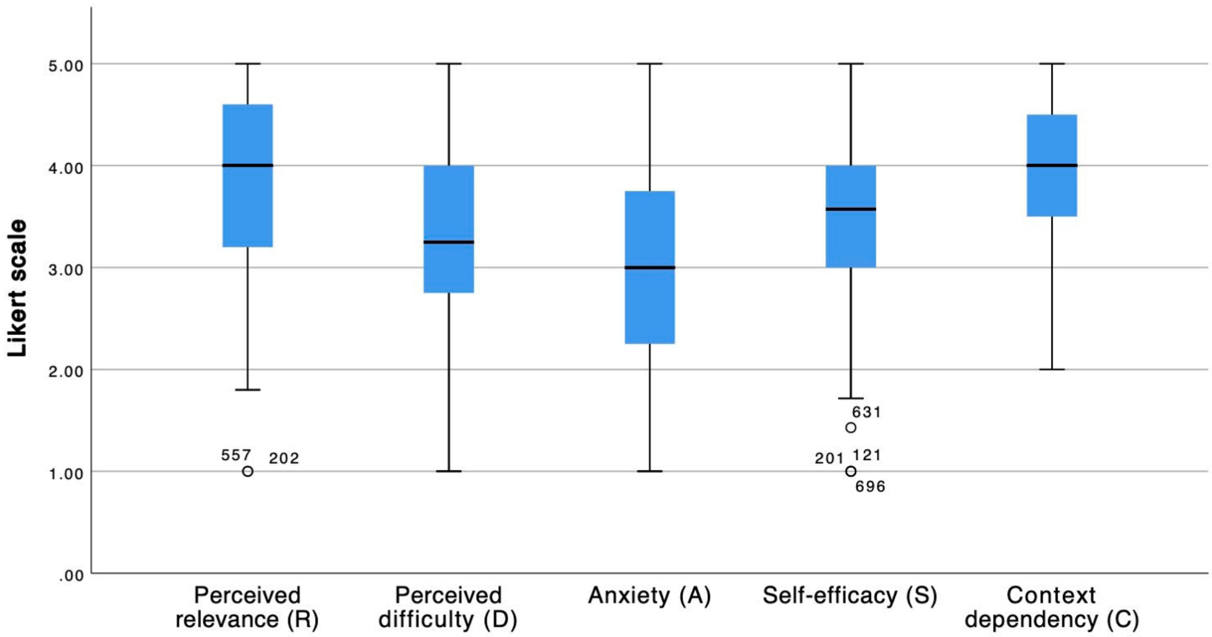

Figure 2: Box and Whisker Plots of Distributions of Five Factors: Anxiety (*A*), Context Dependency (*C*), Perceived Difficulty (*D*), Perceived Relevance (*R*), Self-efficacy (*S*)

Regarding cognitive beliefs, *Perceived relevance* (*R*) showed a first quartile (*Q1*) of about 3.25. In other words, over 75% of participating teachers acknowledged the critical role of ISE in enhancing students' lives and learning outcomes, as well as positively contributing to their professional development. Participants specifically highlighted their belief that "ISE is essential for making students more involved in technological and socio-scientific problems in society", and that "inexperienced teachers should receive preparation training on ISE". This underscores the high value teachers place on ISE for shaping student engagement and their own career trajectories. For the perceived *difficulty* dimension (*D)*, *Q2* (median) is about 3.30, indicating that nearly half of the participants found integrated science pedagogy challenging. Despite recognizing its value, they noted several specific difficulties that hindered their implementation of ISE, with participants underscoring challenges such as finding topics "complicated," struggling to "employ learner-centered teaching methods," and encountering difficulty "to design and implement scientific inquiry practices in my science class."

Anxiety is a significant affective component of attitudes and attitudinal theories because it directly influences an individual's emotional response to a particular object, situation, or behavior, shaping how attitudes are formed and expressed. Given the remarkable level of perceived difficulty, it is reasonable that the lowest mean was the *anxiety* dimension (*A*). Its median of 3.00 indicated that 50% of participants acknowledged experiencing stress during ISE implementation. This finding suggests that despite its adoption, many teachers approach integrated science with a sense of emotional discomfort, reflecting the significant role anxiety plays in shaping their attitudes toward ISE.

Despite the specific difficulties encountered during ISE implementation, participants reported a high level of *self-efficacy* (*S*), one of the perceived control aspects, with 75% of participants expressing a strong belief in their capability to perform ISE (*Q1* = 3.00). This finding is particularly notable given that only one-third of the total had received formal professional development to be certified. They showed high confidence in their ability to "integrate disciplines and/ or technology contents" and "deal with questions about integrated science from students".

Lastly, the highest-scoring factor was *contextual dependency* (*C*), which highlights how external factors and situational constraints critically shape a teacher's attitude toward implementing ISE. Our findings show that over 75% of participants strongly agree that these contextual factors are highly influential. They emphasized the importance of access to resources, such as information and teaching materials, as well as support from colleagues and the school. This suggests that a lack of resources and support is a major barrier, and providing these elements may be the single most decisive factor for successful ISE implementation.

However, consistently high standard deviations reflect limited participant consensus. This variability, potentially driven by demographic diversity, justifies the examination of individual factors undertaken in RQ2.

RQ2: What contextual factors shape Vietnamese science teachers' attitudes toward teaching integrated science?

RQ2 was addressed using one-way ANOVA (see Table 3 and Table 4) and post hoc comparisons (see Table 5). Prior to conducting the one-way ANOVA, the underlying statistical assumptions were carefully assessed. The normality of the samples was examined, and the results confirmed that the distributions did not deviate significantly from normality. In addition, the assumption of homogeneity of variances was tested and found to be satisfied, indicating that variances across the groups were equivalent. Taken together, these results confirmed that the assumptions for conducting a one-way ANOVA were fulfilled.

Overall, teachers' attitudes towards integrated science teaching were largely consistent across subsamples, except for the professional development and school-level groups. There were no significant differences in attitudinal scores between male and female teachers. Similar trends were observed for teaching experience and educational level backgrounds (see Table 4).

On the other hand, participations in professional development (PD) indicated statistically significant difference among three subgroups at the $p < .05$ level in three dimensions: perceived difficulty (*D*: $F = 4.129$, $p = .017$), anxiety (*A*: $F = 3.676$, $p = .027$), self-efficacy (*S*: $F = 14.025$, $p < .001$).

For perceived difficulty, a significant difference was observed between teachers who participated in PD and demonstrated proficiency in ISE knowledge or execution competence ($M = 3.00$, $SD = 1.11$) and those who did not participate in PD ($M = 3.45$, $SD = 0.95$). Teachers who participated in PD but exhibited lower ISE knowledge proficiency or execution competence scored the highest in the anxiety dimension ($M = 3.13$, $SD = 0.98$), indicating greater anxiety compared to the other groups, particularly those with high proficiency.

Regarding self-efficacy, post hoc comparisons in Table 5 revealed that teachers who participated in training and demonstrated ISE proficiency ($M = 3.85$, $SD = 0.75$) had significantly higher self-efficacy scores than those who attended training but achieved lower proficiency ($M = 3.28$, $SD = 0.94$) or those who had not participated in training at all ($M = 3.18$, $SD = 0.99$). These results, summarized in Table 3, suggest that teachers who received sufficient training and attained high ISE proficiency generally exhibited more positive attitudes toward integrated science teaching, whereas those with less training or proficiency experienced heightened anxiety and perceived greater difficulty.

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Variable	*n*	The relevance and importance (*R*)		The perceived difficulty (*D*)		Anxiety (*A*)		Self-efficacy (*S*)		Perceived dependence on context factor (*C*)	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	203	3.89	0.97	3.25	1.04	2.96	1.06	3.41	0.95	3.95	0.90
Gender											
Male	48	3.86	0.96	3.19	1.01	2.94	1.03	3.45	0.93	3.92	0.89
Female	155	3.97	1.02	3.45	1.10	3.01	1.16	3.31	1.01	4.04	0.92
Teaching Experience											
< 5 years	68	4.05	0.88	3.28	1.08	2.90	1.07	3.45	0.88	4.01	0.88
5-10 years	57	3.89	0.93	3.37	0.90	3.06	1.01	3.55	0.86	3.97	0.83
> 10 years	78	3.74	1.06	3.14	1.09	2.93	1.10	3.29	1.06	3.88	0.97
Professional Development											
Not participating	69	3.80	1.06	3.45	0.95	3.00	1.11	3.18	0.99	3.99	0.89
Participated but not yet proficient	75	3.84	0.99	3.27	1.03	3.13	0.98	3.28	0.94	3.88	0.93
Participated and proficient	59	4.04	0.82	3.00	1.11	2.69	1.06	3.85	0.75	3.99	0.88
Education Level											
Undergraduate degree	157	3.88	1.02	3.20	1.08	2.94	1.07	3.42	0.99	3.94	0.93
Postgraduate degree	46	3.92	0.80	3.45	0.87	3.02	1.04	3.39	0.79	3.98	0.79
School Level											
Primary school	41	4.06	0.86	3.13	1.04	2.89	0.95	3.36	1.00	3.88	0.96
Secondary school	94	3.71	1.04	3.12	1.08	3.01	1.08	3.40	0.98	3.91	0.94
High school	43	3.97	0.93	3.45	0.95	2.94	1.09	3.41	0.84	3.93	0.84
Inter-level Secondary school & High school	25	4.10	0.88	3.63	0.86	2.90	1.13	3.55	0.96	4.26	0.67

Table 3: Teachers' Attitudes Based on Gender, Educational Background, Teaching Experience, and Educational Institution.

Variable	Gender		Teaching experience		Professional development		Education level		School level	
	F(*p*)	η^2	*F*(*p*)	η^2	*F*(*p*)	η^2	*F*(*p*)	η^2	*F*(*p*)	η^2
Perceived relevance (*R*)	0.609 (.436)	.126	2.548 (.081)	.098	1.476 (.231)	.090	.100 (.752)	.102	2.557 (.056)	.172
Perceived difficulty (*D*)	3.018 (.084)	.085	1.049 (.352)	.087	4.129 (.017)	.112	2.642 (.106)	.065	3.066 (.029)	.076
Anxiety (*A*)	.199 (.656)	.088	.452 (.637)	.055	3.676 (.027)	.077	.232 (.630)	.066	.202 (.895)	.078
Self-efficacy (*S*)	1.040 (.309)	.138	1.833 (.163)	.091	14.025 (.000)	.200	.043 (.835)	.131	.300 (.826)	.123
Context dependence (*C*)	.857 (.356)	.060	.562 (.571)	.097	.540 (.584)	.068	.083 (.773)	.091	1.735 (.161)	.073

Note: Values in bold indicate significance at the p < .05 level.

Table 4: Differences between Groups in terms of Overall Teachers' Attitudes toward Integrated Science

Background characteristics		Perceived relevance (R)		Perceived difficulty (D)		Anxiety (A)		Self-efficacy (S)		Context dependence (C)	
(*I*)	(*J*)	(*I-J*)	SE	(*I-J*)	SE	(*I-J*)	SE	(*I-J*)	SE	(*I-J*)	SE
Professional Development	**Professional Development**										
Not participating	Participated but not yet proficient	-.04	0.142	0.18	0.151	-0.14	0.156	-0.10	0.127	0.11	0.123
Not participating	Participated and proficient	-.24	0.151	**0.45**	**0.161**	0.31	0.166	**-0.66**	**0.135**	0.01	0.130
Participated but not yet proficient	Participated and proficient	-.20	0.148	0.27	0.158	**0.45**	**0.163**	**-0.56**	**0.132**	-0.10	0.128
School Level	**School Level**										
Primary school	Secondary school	.35	.158	.01	.170	-0.12	.179	-0.05	.152	-0.02	.137
Primary school	High school	.09	.184	-.32	.198	-0.05	.208	-0.05	.177	-0.05	.159
Primary school	Inter-level secondary school & high school	-.03	.214	-.50	.230	-0.01	.242	-0.19	.205	-0.38	.185
Secondary school	High school	-.26	.155	-.33	.167	0.07	.176	0.00	.149	-0.02	.134
Secondary school	Inter-level secondary school & high school	-.38	.190	-.51	.204	0.11	.215	-0.14	.182	-0.35	.164
High school	Inter-level secondary school & high school	-.12	0.212	-0.18	0.228	0.04	0.240	-0.14	0.204	-0.33	0.184

Note: Values in bold indicate significance at p < .05 level. (I-J) = Mean Difference, SE = Standard Error

Table 5: Post hoc Comparisons in Overall Teachers' Attitudes toward Integrated Science

Besides, teachers from different school levels also showed a significant difference at the < .05 level in their *perceived difficulty* of integrated science (*D*: $F = 3.066$, $p = .029$). However, no clear evidence of specific differences between pairs of school-level subgroups emerged, and the mean scores presented in Table 3 already illustrate the observed variations.

DISCUSSION

Our study adopted the constructs of attitudes from Thibaut et al. (2018, 2019) to examine teachers' attitudes towards ISE and the contextual factors related to these attitudes. From the perspective of educational and scientific efficiency, ISE offers a way to organize STEM learning that reduces fragmentation across disciplines and promotes the transfer of concepts and skills across subject boundaries. Our examination of attitudes toward integrated science directly engages with questions of educational efficiency, since insight into teachers' and learners' perceptions of integrated STEM is a necessary foundation for developing instructional models that make optimal use of time, resources, and content.

Our findings indicate that Vietnamese teachers generally show favorable attitudes toward the new general curriculum, appreciating its relevance and significance for human capital development, job prospects, and everyday life, as also noted by a recent study by Pham et al. (2023). Specifically, teacher participants demonstrated significant self-efficacy regarding ISE, believing strongly in its relevance and importance for future skills, as it covers inquiry-based, active, and real-world learning. Our finding warrants further exploration, as it starkly contrasts with the results of Vu (2021) and Thuan and Mau (2021), which highlighted deficiencies in integrated science knowledge among Vietnamese teachers in real-world practice and implicitly suggested that their beliefs and self-efficacy may be illusory.

Despite teachers' highly positive attitudes toward their perceived relevance and self-efficacy, a cautious interpretation is warranted given reported anxiety and implementation difficulties. While anxiety scores were moderate, nearly half of the participants maintained that they had dealt with pedagogical and emotional challenges in pragmatic teaching. Consequently, policymakers and professional development trainers are reminded to closely monitor the current and future changes in teaching attitudes toward ISE. One potential recommendation is to focus on educators' emotional states alongside collegial support (Ualesi and Ward, 2018) or to promote the implementation of ISE by incorporating inquiry-based techniques and a student-centered methodology through increased modeling and scaffolding via teacher-practitioner inquiry shadowing. Teacher-practitioner inquiry shadowing entails a reflective, systematic approach among ISE experts and in-service teachers, in which teachers are guided to examine their own practices to improve teaching efficacy, address classroom challenges, and deepen their educational knowledge (Dinh and Nguyen, 2023).

As for the governmental level of support, supplying educators with contextually relevant educational resources, such as experienced teacher-generated lesson templates or culturally tailored pedagogical strategies for Vietnamese lesson planning, including textbooks and research-based or theoretical references, presents a promising avenue for experimentation more than co-teaching (Dinh, 2023; Nguyen et al., 2020). Other options to explore include integrated science textbooks (Winarno, 2020) and hands-on science teaching kits or equipment, since most available textbooks are collections of individual chapters from specialized subjects rather than demonstrating integration (Nguyen et al., 2020).

Regarding RQ2, our findings clarify the relationship between teacher attitudes and contextual factors. This study enriches the existing literature by providing critical empirical evidence specifically within the context of a developing country. Specifically, this study found contrastive findings with other studies cited above (e.g., Al Salami et al., 2017; Margot and Kettler, 2019). Herein, there was no statistically significant difference in teachers' attitudes toward ISE based on their gender, years of teaching experience, or educational level. Recently, Pillai et al. (2022) found a significant relationship between teacher demographics (gender, years of experience, and training) and attitudes toward educational reform in Vietnam. However, our findings contradict this, as our participants' attitudes toward ISE showed no such associations. This disparity suggests that the increased complexity of ISE, involving substantial changes in content knowledge (conceptual structure), pedagogical skills, and teaching resources, may attenuate the effects of demographic variables. Our findings also contradict those of Thi To Khuyen et al. (2020), who reported that science teachers' views on integrated STEM education varied by educational background, yet our findings and theirs are consistent in that there were no differences in perceived difficulties across groups with different teaching experience.

Indeed, our research findings indicate that high-quality *professional development* (PD), which leads to greater knowledge retention and execution competence among attendees, is *a major factor* in alleviating science *teachers' perceived difficulty*, *anxiety*, and *reduced self-efficacy*. In other words, teachers who have been trained yet display low proficiency and execution competence after the training are most likely to experience heightened anxiety when teaching integrated science. Most importantly, this finding corresponds with several cited studies above that teachers' attitudes, especially their affective states, must be considered prior to any PD in ISE (cf. Aldahmash et al., 2019; Dinh and Nguyen, 2023; Thibaut et al., 2019; Thi To Khuyen et al., 2020; van Aalderen-Smeets and Walma van der Molen, 2015). Specifically, our finding echoed the emphasis of Ualesi and Ward (2018) and Thibaut et al. (2018) on the necessity of ensuring consistent and thorough PD; they highlighted that the quality of PD must include management support, peer collaboration, and structured guidance to effectively transition from traditional didactic teaching to a reformed, student-centered teaching style.

Additionally, our findings are also significant because, despite the existence of various teacher education or training programs (Nguyen and Pham, 2021; Nguyen et al., 2020), the low efficiency of ISE implementation can be attributed to the fact that the knowledge retention and execution competence of the participating teachers have not been adequately monitored and evaluated. To assess teachers' knowledge retention and competence, the following abilities may be evaluated via peer observation or teachers' annual assessment: the capacity to implement integrated science knowledge, the ability to connect lessons to students' everyday problem-solving scenarios, the pedagogical skill in delivering knowledge through a student-centered teaching approach rather than traditional lecturing, and the skill to design activities that adhere to a scientific inquiry-based framework, facilitating students' application of knowledge to real-world contexts.

Third, although there was no clear evidence of specific differences between pairs of school-level subgroups, the mean scores for perceived difficulties in ISE showed some variation, especially among secondary school teachers. As Weinberg and Sample McMeeking (2017) pointed out, secondary school teachers see themselves as experts in their own content; yet, they frequently regard themselves as lacking proficiency in other fields and feel deprived of appropriate and supportive curriculum materials. In Vietnam, secondary teachers face additional problems during the transition to integrated science, as the traditional national curriculum historically fragmented science into distinct subjects upon leaving elementary school. Currently, this divide tends to be eradicated, leading instructors to feel that ISE is perplexed and to perceive ISE preparation as increasingly daunting. Therefore, our findings call for further exploration in future research, as they may still indicate the need for targeted professional development or resources tailored to address their specific challenges and perceptions at different school levels. Professional development should also be applied consistently across school levels; if district and school leaders ensure that science teachers attain competence in ISE through frequent training, disparities in ISE implementation across different school levels can be mitigated (Nguyen et al., 2020; Whitworth and Chiu, 2015).

Finally, a deeper analysis of the link between the teachers' claimed self-efficacy and their actual classroom practices is also limited. While the questionnaire-based methodology was effective for identifying broad attitudinal trends, it was insufficient to demonstrate how self-reported confidence translates into observable instructional behaviors. Moreover, the cross-sectional design and the restricted sample of in-service Vietnamese teachers constrain the generalizability of the findings beyond this context and prevent causal inferences about changes in attitudes over time. More research can help fill this methodological gap by considering mixed-methods designs or by widening the target populations of teachers.

CONCLUSION

While Integrated Science Education (ISE) is proven to enhance student outcomes, developing countries such as Vietnam face substantial implementation hurdles. The persistence of traditional, single-discipline curricula has resulted in a lack of pedagogical strategies necessary to sustain ISE in K-12 schools. This quantitative research, therefore, investigates the attitudes of science teachers with different demographic backgrounds towards ISE, within the context of a top-down educational reform implemented by the Ministry of Education, a centralized national educational leadership. Our findings thus are significant because they highlight that the limited efficiency of ISE implementation in Vietnam is associated with both the availability of teacher training programs and the lack of systematic monitoring and evaluation of teachers' knowledge and execution competence. Moreover, understanding science teachers' perspectives on the transition from specialization to ISE through a contextualized lens offers indispensable insights into the specific challenges and opportunities for integration, enabling targeted, impactful interventions from the school level to statewide or national policymaking. Unlike previous studies, the contextual factors, such as gender, teaching experience, and educational levels, do not matter. Rather, in a developing country setting, the quality of professional development and, to some degree, school levels are crucial contextual factors associated with teachers' attitudes towards transformative ISE, addressing public concerns around the integration method in educational reform.

Consequently, a critical lesson for advancing ISE is that priority must be given to high-quality professional development tailored to specific school levels and aligned with systemic reforms. Future research should focus on designing and validating these targeted professional development initiatives to address the urgent, distinct challenges facing teachers.

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Full research paper

DEVELOPMENT OF THE FOUR-TIER DIAGNOSTIC TEST TO IDENTIFY STUDENT MISCONCEPTIONS IN THE STATIC FLUIDS CHAPTER

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ABSTRACT

Misconceptions about static fluid concepts in physics are common among students, making it essential for teachers to identify and address them. This research aims to develop and evaluate the quality of a four-tier diagnostic test instrument and identify student misconceptions in the static fluid chapter. The sample for this research comprised 91 grade 11 students from the State Madrasah Aliyah in Bantul, Indonesia, selected using a purposive sampling technique. The findings of this research indicate that the four-tier diagnostic test instrument is suitable for identifying student misconceptions. The test validation results showed 17 valid test items and 1 invalid test item. This diagnostic test is reliable, with a person reliability coefficient of 0.73, an item reliability coefficient of 0.96, and a Cronbach's alpha coefficient of 0.72. The test items include two very difficult, seven difficult, and nine moderate items. The discrimination power of the 17 test items is good, except for one, which is poor. This instrument also found that the most common student misconceptions were in the hydrostatic pressure sub-chapter (71% of students) and in surface tension (66% of students).

KEYWORDS

Conceptual understanding, four-tier diagnostic test, misconceptions, static fluids, Winstep software

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Highlights

- *A Rasch-validated four-tier diagnostic test effectively detects students' misconceptions in static fluid concepts.*
- *Students exhibit high-confidence misconceptions predominantly in hydrostatic pressure and surface tension topics.*
- *Competency-based diagnostic mapping provides actionable evidence for targeted and efficient instructional remediation.*

INTRODUCTION

Physics is a field of knowledge that focuses on natural phenomena (Kösem and Özdemir, 2014). Before being formally taught in schools, students already have an initial understanding of basic physics concepts through their experiences with natural phenomena in everyday life. Understanding physics concepts is key to success in physics learning (Cai et al., 2021). Students' conceptual understanding includes their comprehension of a concept, especially in the context of physics, which enables them to express it, depict it in various forms of representation, provide examples related to the concept, and apply it to solve everyday problems (Ozkan and Selcuk, 2015). Concepts in physics have been clearly articulated and accepted by scientists. If someone has personal interpretations or understanding of these concepts, it is referred to as conceptions.

Concepts are crucial components for students. Students can develop conceptual understanding through school experiences or daily activities (Maknun, 2020). Students' diverse experiences can influence whether they understand concepts through scientific conceptions (Mason and Just, 2016). There is a correlation between conceptual understanding and misconceptions. Misconceptions are concepts in students' minds that may not align with expert concepts, potentially misleading students' learning (Dack, 2019). Misconceptions arise when students' prior knowledge deviates from scientifically accepted concepts (Hill and Chin, 2018). Misconceptions can manifest as errors in initial understanding, errors in linking different concepts, and inappropriate ideas. Students' misconceptions can also stem from various factors, such as internal factors, teacher negligence, deficiencies in textbooks, contextual issues, and mismatches in the teaching methods used by teachers during the learning process (Suprapto, 2020). Teachers need to address these misconceptions, as they can hinder students' ability to receive and assimilate new knowledge, ultimately affecting students' success in the learning process (Assem et al., 2023). Neglecting students' conceptions in learning activities can make the learning process difficult for students, thus potentially lowering their learning achievements by up to 80% below the minimum completion (Neito et al., 2025). The danger of misconceptions becomes more serious if left unaddressed, as they can affect students' understanding of future concepts (Hasanah, 2020). Teachers must understand and detect students' misconceptions to help them overcome them effectively.

However, a few teachers, around fewer than 50%, still pay attention to methods of identifying and resolving student misconceptions (Robbins et al., 2025). This indication is also evident from initial interviews conducted at one of the MAN (Islamic Senior High School) in the Bantul region. The results of interviews with physics teachers indicate that student learning outcomes in static fluids remain low, with only 40% of students completing the material. Additionally, physics teachers at the MAN had never used the four-tier diagnostic test to identify student misconceptions, and these misconceptions usually surfaced when students asked questions or expressed their understanding. This was found by teachers accidentally. However, this method is ineffective because most students feel embarrassed and reluctant to ask the teacher further questions about concepts they do not understand.

Several methods can be used to evaluate students' understanding and misconceptions, including concept mapping, concept-related interviews, and diagnostic test instruments. One common approach to identifying student misconceptions is the use of diagnostic tests, according to Taslidere (2016), which are evaluations designed to identify students' weaknesses and facilitate appropriate improvement. Diagnostic tests also aim to evaluate indications such as conceptual understanding, misconceptions, and a lack of understanding of concepts. Some variants of multiple-choice diagnostic tests include one-tier, two-tier, three-tier, and four-tier diagnostic tests (Türkoguz, 2020). The four-tier diagnostic test is one diagnostic test that can identify misconceptions. The four-tier diagnostic test was developed from the three-tier multiple-choice diagnostic test (Istiyono et al., 2023). The development lies in adding students' confidence in choosing answers and reasons. The first tier consists of multiple-choice questions with three distractors and one correct answer, which students must select. The second tier assesses students' confidence levels in the chosen answer. The third tier evaluates students' reasons for answering questions, with four provided options. The fourth tier assesses students' confidence levels in choosing those reasons (Caleon and Subramaniam, 2010).

In addition, this study adopted a four-level diagnostic test instrument because it has several advantages. The four-tier diagnostic test instrument has several advantages, including its ability to differentiate more deeply between students' confidence levels in their answers and the reasons they chose (Madina et al., 2022). Providing a more comprehensive diagnosis related to student misconceptions. Identifying more accurately the parts of the material that require additional attention and assisting in planning more effective learning to address student misconceptions (Wahyuni et al., 2021). Meanwhile, this study aims to construct and test the feasibility of a four-tier diagnostic test instrument. To identify misconceptions of grade XI students regarding static fluid using a four-level diagnostic test instrument.

Problem statement

Physics learning in schools often faces challenges, including students' misconceptions. These misconceptions arise because students initially understand physics concepts through everyday experiences before receiving formal learning. This understanding does not always align with the scientific concepts accepted by experts, which can hinder students' learning process. According to Caleon and Subramaniam (2010), misconceptions that are not properly addressed can interfere with the understanding of advanced concepts and affect student learning outcomes. In line with this statement, one of the physics materials that often experiences misconceptions is static fluid. Research by Putra et al. (2020) shows that students have difficulty understanding the concept of hydrostatic pressure and Pascal's law. This is due to the wrong initial understanding and ineffective learning methods for identifying and overcoming these misconceptions. In addition, teachers are often unaware of misconceptions because the evaluation tools available to them do not adequately assess students' understanding in depth. Thus, to overcome this problem, an evaluation instrument is needed that accurately identifies students' misconceptions. The four-tier diagnostic test is an effective tool in revealing students' misconceptions. This test not only assesses students' answers but also their reasons and confidence level in those answers. According to research by Çelikkanlı and Kızılcık (2022), the use of a four-tier diagnostic test can help teachers design more targeted learning strategies to address students' misconceptions. However, the implementation of this test remains limited in educational settings, so further efforts are needed to develop and apply it more widely in physics learning.

METHOD

Research design

This study adopts a research and development (R&D) approach to design and validate an innovative diagnostic tool addressing student misconceptions about the static fluid concept in physics. Meanwhile, the research model used is the development study model, which aims to address educational problems, particularly student misconceptions, by developing an evaluation tool (Van den Akker et al., 2006). The first stage of this development study is the preliminary research phase, which includes a literature review and field surveys. The second stage is the prototype development stage, which includes creating, validating, and revising the four-tier instrument. The third stage is the summative evaluation, which encompasses both limited and extensive testing. During the testing stage of the four-tier diagnostic test, a pre-experimental single-group post-test design was used (Setiawan et al., 2019). This design was chosen to measure students' misconceptions about the static fluids chapter using a four-tier diagnostic test after students received instruction on the physics topic. Meanwhile, the fourth or final stage is the systematic reflection and documentation stage, which involves reporting the research.

Participants

The test subjects in this study were selected using a purposive sampling method. The decision to use purposive sampling was made because all test subjects had studied the static fluid chapter (Maison et al., 2020). Class XI MIPA 1 was chosen as the subject for limited testing, while XI MIPA 2 and XI MIPA 3 were chosen for extensive testing. They selected class XI because they had studied the static fluid chapter. Additionally, based on interviews with physics teachers at one of the MANs in Bantul, it was found that students' learning outcomes in the static fluid chapter remained low, with student completion rates of only 40%. This indicates students' misconceptions about static fluid chapters. Information regarding the number of students can be found in Table 1.

Class	Total Students
XI MIPA 1	26
XI MIPA 2	32
XI MIPA 3	33
Total	91

Table 1: Subject profile of research on identifying static fluid misconceptions

Instrument and procedures

Students' misconceptions about static fluids are measured using a four-tier diagnostic test. Researchers and participants followed ethical procedures throughout data collection. The initial stage of this research was to develop a four-tier diagnostic test instrument to measure student misconceptions in the chapter on static fluids, which is valid and reliable. The researchers developed a new instrument to ensure that the four-tier diagnostic test instrument was relevant to the research objective of measuring students' misconceptions in the static fluid chapter.

A literature review on static fluids was conducted before designing the four-tier diagnostic test instrument. In the static fluid chapter, six sub-chapters serve as the basis for developing four-tier diagnostic test instruments: density, hydrostatic pressure, Archimedes' law, surface tension, capillarity, and viscosity (Asrizal et al., 2022; Kundu et al., 2015). Furthermore, a four-tier diagnostic test instrument was developed to measure students' misconceptions about static fluids, comprising 18 items. The test instruments developed are then validated by five expert validators before being distributed to students. In general, the procedures carried out in this research can be illustrated in Figure 1.

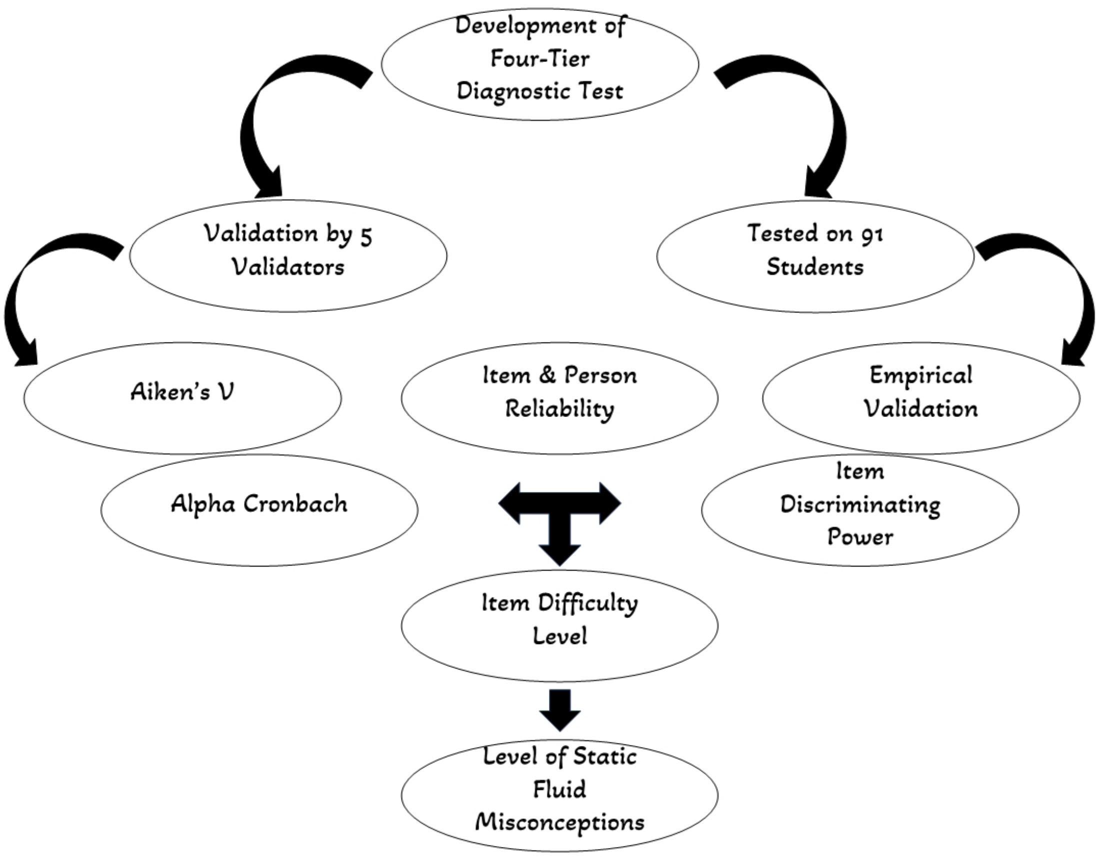

Figure 1: the process of developing an instrument to identify static fluid misconceptions

Based on Figure 1, which outlines the flow of this research process, in analyzing student misconceptions, a combination of the four-tier diagnostic test answer categories presented in Table 2 can be used (Yuberti et al., 2020).

No.	Category	Combination Answers				Score
		Answers	Confidence Level	Reason	Confidence Level	
1.	Understanding of Concept (UC)	Correct	Sure	Correct	Sure	4
2.	Partially Understand (PU)	Correct	Sure	Correct	Unsure	3
3.	Partially Understand (PU)	Correct	Unsure	Correct	Sure	3
4.	Partially Understand (PU)	Correct	Unsure	Correct	Unsure	3
5.	Partially Understand (PU)	Correct	Sure	Wrong	Sure	3
6.	Partially Understand (PU)	Correct	Sure	Wrong	Unsure	3
7.	Partially Understand (PU)	Correct	Unsure	Wrong	Sure	3
8.	Partially Understand (PU)	Correct	Unsure	Wrong	Unsure	3
9.	Partially Understand (PU)	Wrong	Sure	Correct	Sure	3
10.	Partially Understand (PU)	Wrong	Sure	Correct	Unsure	3
11.	Partially Understand (PU)	Wrong	Unsure	Correct	Sure	3
12.	Partially Understand (PU)	Wrong	Unsure	Correct	Unsure	3
13.	Misconceptions (M)	Wrong	Sure	Wrong	Sure	2
14.	Don't Understand of Concept (DUC)	Wrong	Sure	Wrong	Unsure	1
15.	Don't Understand of Concept (DUC)	Wrong	Unsure	Wrong	Sure	1
16.	Don't Understand of Concept (DUC)	Wrong	Unsure	Wrong	Unsure	1
17.	Cannot Be Encoded (CBE)	Some tiers are not answered, or more than one option is available	Some tiers are not answered, or more than one option is available	Some tiers are not answered, or more than one option is available	Some tiers are not answered, or more than one option is available	0

Table 2: Categories of combination answers in the four-tier diagnostic test

Based on the four-tier diagnostic test instrument developed, it is more closely aligned with the ability to solve physics problems. However, students not only choose the correct answer and reason, but also believe in them.

Validity and reliability of the four-tier diagnostic test

Five expert validators, including two lecturers, two physics teachers, and one colleague (a physics education practitioner), first tested the four-tier diagnostic test instrument for validity and reliability. The validity test of this four-tier diagnostic test instrument includes a content validity test and an empirical validity test. Content validity is analyzed using Aiken's V equation. An item in the content validity test is considered valid if the calculated Aiken's V coefficient value is greater than or equal to the minimum value listed in Aiken's table (Aiken, 1985). The results of the content validity analysis of the four-tier diagnostic test items can be shown in Table 3.

Based on Table 3, all four-tier diagnostic test items were declared valid with revisions by the five validators. The items can be tested on students after being revised based on the validator's suggestions. Based on the results of limited trials, an empirical validity analysis can be conducted to assess the suitability of each item with the fit model (Van Laar et al., 2018). The empirical validity of each item can be assessed by reviewing the WINSTEPS program output, including MNSQ, ZTSD, and Pt Measure Correlation values. Outfit Mean Square (MNSQ) is a component of empirical validity that measures how much the data deviate from the Rasch model, especially in cases of extreme misfit (e.g., answers that do not match the questions, or questions that are too easy or too difficult). Outfit Z-standard (ZTSD) transforms the Outfit MNSQ value into a standard z score, which follows a normal distribution. Meanwhile, Point Measure Correlation (Pt Measure Correlation) is the correlation between responses to specific items and participants' total ability, as defined by the Rasch model (Lee et al., 2020). Meanwhile, empirical validity can be assessed using the results of limited trials, as shown in Table 4. Based on Table 4, 17 items are empirically valid, but 1 item, item 5, is declared invalid. Questions with invalid criteria cannot be used and are discarded in extensive trials. Meanwhile, the reliability of the four-tier diagnostic test was assessed using the item separation index (item estimation) and the person separation index (case estimation) in the WINSTEPS program (Laliyo et al., 2021). The greater the item separation index value, the greater the accuracy of the test items using the PCM model. In addition, the higher the person-separation index value, the greater the consistency of each item in measuring people's abilities (Lightfoot et al., 2021). The reliability of the four-tier diagnostic test was also analyzed using Cronbach's Alpha equation. Cronbach's Alpha measures the interaction between the subjects and the items (Vaske et al., 2017). Meanwhile, the reliability analysis results for the four-tier diagnostic test items are shown in Table 5.

Item	Aiken's V Coefficient	Criteria
1	0.83	Valid
2	0.80	Valid
3	0.85	Valid
4	0.80	Valid
5	0.80	Valid
6	0.81	Valid
7	0.81	Valid
8	0.82	Valid
9	0.82	Valid
10	0.80	Valid
11	0.85	Valid
12	0.84	Valid
13	0.83	Valid
14	0.83	Valid
15	0.83	Valid
16	0.81	Valid
17	0.85	Valid
18	0.84	Valid

Table 3: Content validity results of four-tier diagnostic test items

Item	MNSQ	ZTSD	Pt Measure Correlation	Criteria
1	0.92	-0.2	0.33	Valid
2	1.39	1.1	0.40	Valid
3	1.59	2.0	-0.20	Valid
4	0.73	-0.7	0.42	Valid
5	**0.42**	**-2.9**	**0.27**	**Invalid**
6	1.34	1.3	-0.27	Valid
7	0.98	0.1	0.69	Valid
8	1.04	0.3	0.30	Valid
9	1.02	0.2	0.60	Valid
10	1.08	0.4	0.38	Valid
11	0.74	-1.1	0.38	Valid
12	0.93	-0.2	0.80	Valid
13	1.11	0.5	0.59	Valid
14	1.13	0.5	0.62	Valid
15	0.82	-0.7	0.26	Valid
16	0.73	-1.1	0.47	Valid
17	0.77	-0.8	0.29	Valid
18	0.67	-1.0	0.80	Valid

Table 4: Empirical validity results of four-tier diagnostic test items

Limited Trial			
Reliability Type	**Reliability Coefficient**	**Information**	**Criteria**
Person reliability	0.72	Reliable	Moderate
Alpha Cronbach	0.74	Reliable	Good
Item Reliability	0.90	Reliable	Good
Extensive Trial			
Reliability Type	**Reliability Coefficient**	**Information**	**Criteria**
Person reliability	0.73	Reliable	Moderate
Alpha Cronbach	0.72	Reliable	Good
Item Reliability	0.96	Reliable	Excellent

Table 5: Reliability results of four-tier diagnostic test items

Based on Table 5, the reliability values, including person reliability, item reliability, and Cronbach's alpha, are all reliable. This means that the developed four-tier instrument can be used to identify students' misconceptions about static fluid chapters.

Difficulty level and differentiating power of the four-tier diagnostic test

Test items are effective when their difficulty is balanced, neither too easy nor too difficult. A moderate difficulty level is optimal because it encourages students to apply more effort in solving problems (Hong et al., 2021). Test items that are too easy tend to make students less likely to improve their understanding, while those that are too difficult cause students to lose enthusiasm and feel inadequate (Lourdusamy and Magendiran, 2021). The difficulty level of the four-tier diagnostic test in this study was analyzed using the WINSTEPS program. The item difficulty index is obtained from item statistical output, which includes the item score or the number of students who answered correctly, and the logit measure for each item (Saidi and Siew, 2019). The criteria for the logit measure values of the test items are shown in Table 6.

Logit Measure Value	Criteria
> +1.37 SD	Very Difficult
0.00 to +1.37 SD	Difficult
-1.37 SD to 0.00	Moderate
< -1.37 SD	Easy

Table 6: Conditions for logit measure values

The item difficulty level test was conducted to evaluate the quality of the four-tier diagnostic test items. Test items are considered good if the difficulty level is adequate or moderate (Bichi and Talib, 2018). Meanwhile, analysis of the test's differentiating power assesses its ability to separate students with high abilities from those with low abilities (Machts et al., 2016). If students with both high and low ability can answer a test item correctly, then the test item is considered ineffective because it lacks differentiating power. On the other hand, if all students in the low and high groups give incorrect answers, the test items lack differentiating power (Rabin et al., 2021). The differentiating ability of each test item was analyzed using the WINSTEPS program. Analysis of the test items' differentiating power is reflected in the DIF output, with a focus on the resulting probability values. An item is considered to have good discriminating power if the resulting probability value is greater than 0.05 (Iqbal and Malzahn, 2017). An item can be relied upon as a data collection tool if it has sufficient item-distinguishing power.

Data analysis

The analysis used to identify student misconceptions in the static fluid chapter measured students' conceptual understanding levels as percentages. Student misconceptions are identified by paying attention to student answers, which can be grouped based on Table 2 (Saricayir et al., 2016). Meanwhile, the percentage of students' understanding of concepts in the static fluid chapter can be calculated using the equation presented in Table 7.

Category	Analytical Equations	Information
Understanding of Concept (*UC*)	$UC = \frac{n_{UC}}{N} \times 100\%$	n_{UC} is the number of students experiencing UC
Partially Understand (*PU*)	$PU = \frac{n_{PU}}{N} \times 100\%$	n_{PU} is the number of students experiencing PU
Misconceptions (*M*)	$M = \frac{n_{M}}{N} \times 100\%$	n_{M} is the number of students experiencing M
Don't Understand of Concept (*DUC*)	$DUC = \frac{n_{DUC}}{N} \times 100\%$	n_{DUC} is the number of students experiencing DUC

Note: N is the total number of students

Table 7: Equation of concept understanding level analysis

RESULTS

The results of this research include the construct results, the quality of the four-tier diagnostic test instrument, and the identification of class XI students' misconceptions regarding static fluids. The results obtained from this research are a development of the four-tier diagnostic test instrument that has been tested.

Four-tier diagnostic test instrument construction

The construct results found that the four-tier diagnostic test instrument developed consisted of 17 questions grouped into six indicators of competency achievement. The four-tier diagnostic test instrument includes a test question grid, work instructions, an answer key, an answer sheet, and scoring guidelines. The grouping of four-tier diagnostic test instrument

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questions into six indicators of competency achievement is shown in Table 8.

Based on Table 8, the most common four-tier diagnostic test items are on hydrostatic pressure. This is because the concept is still a physics concept that students find difficult to understand in the static fluid chapter. Furthermore, the preliminary study results also show that students still experience errors when asked to analyze the application of hydrostatic pressure in everyday life. Density, surface tension, and viscosity are static fluid concepts that are difficult to understand under hydrostatic pressure. So, the four-tier diagnostic test items for these three concepts are arranged into three items each. Meanwhile, two four-tier diagnostic tests are formulated based on Archimedes' law and capillarity. This is because the concept of static fluids is easiest for students to understand.

No.	Competence Achievement Indicators (CAI)	Items
1.	Density	5, 13,15
2.	Hydrostatic Pressure	1, 4, 12, 14
3.	Archimedes' Law	3, 9
4.	Surface Tension	7, 10, 11
5.	Capillarity	6, 8
6.	Viscosity	2, 16, 17

Table 8: Grouping of four-tier diagnostic test instrument items

Results of the difficulty level and the differentiating power of the four-tier diagnostic test

Analysis of the difficulty level of test items aims to evaluate their quality as a data-collection tool, with the criterion that they fall into the category of good test questions. A test item is considered good if it has a balanced difficulty level, is neither too easy nor too difficult, or can be categorized as moderate. This study analyzed the difficulty level of four-tier diagnostic test items using the WINSTEPS application, shown in Table 9.

Items	Score 1	Score 2	Score 3	Score 4	Count	Measure	Criteria
11	3	16	6	1	26	1.72	Very Difficult
6	-	20	4	2	26	1.51	Very Difficult
8	4	7	14	1	26	1.24	Difficult
15	-	11	12	3	26	0.84	Difficult
10	2	7	12	5	26	0.70	Difficult
5	-	3	22	1	26	0.42	Difficult
12	3	5	8	10	26	0.34	Difficult
16	1	4	15	6	26	0.27	Difficult
17	1	1	18	6	26	0.04	Difficult
3	2	1	14	9	26	-0.04	Moderate
13	1	5	7	13	26	-0.20	Moderate
14	1	4	5	16	26	-0.56	Moderate
7	1	3	5	17	26	-0.76	Moderate
1	-	1	11	14	26	-0.87	Moderate
18	1	1	7	17	26	-0.98	Moderate
2	1	1	6	18	26	-1.10	Moderate
4	-	-	10	16	26	-1.23	Moderate
9	1	2	2	21	26	-1.36	Moderate

Table 9: Difficulty level of four-tier diagnostic test items

Table 9 shows that the difficulty level evaluation includes two items in the very difficult category: items 6 and 11. There are seven items with a difficult level of difficulty and nine with a medium level of difficulty. Furthermore, the discriminating power of test items reflects a test's ability to differentiate between students with high and low ability. A question is considered to have good discriminating power if the resulting probability value exceeds 0.05. This study analyzed the discriminating power of four-tier diagnostic test items using the WINSTEPS application, presented in Table 10.

Based on the analysis of the differentiating power of the questions in Table 10, 18 questions have logit values above 0.05, indicating that the test items exhibit good quality. Meanwhile, 1 question 14 has a logit value below 0.05. Questions with a logit value below 0.05 are considered to have poor discriminating power. Therefore, revisions are needed to point number 14 so that it can serve as a reliable tool for assessing students' misconceptions in static-fluid chapters.

Item	Aiken's V Coefficient	Criteria
1	0.710	Good
2	0.610	Good
3	0.341	Good
4	0.153	Good
5	0.846	Good
6	0.473	Good
7	0.199	Good
8	0.569	Good
9	0.323	Good
10	0.838	Good
11	0.342	Good
12	0.319	Good
13	0.412	Good
14	0.046	Bad
15	0.739	Good
16	0.669	Good
17	0.576	Good
18	0.691	Good

Table 10: Discriminating power of four-tier diagnostic test items

Results of student misconceptions identification on the static fluid chapter

The results of the analysis of student misconceptions in the static fluid chapter provide information on the number of students and the percentages who understand the concept (UC), partially understand it (PU), hold a misconception (M), and do not understand it (DUC). Table 11 below contains details of the misconceptions of 65 students regarding the chapter on static fluids from grades XI MIPA 2 and XI MIPA 3. This is because grade XI MIPA 1 students were used as participants to assess the instrument's empirical validity.

Competence Achievement Indicators (CAI)	Item	UC		PU		M		DUC	
		Total	%	Total	%	Total	%	Total	%
Density	5	41	63	17	26	7	11	-	-
Density	13	26	40	19	29	11	17	9	14
Density	15	17	26	38	58	5	8	5	8
Hydrostatic Pressure	1	43	66	17	26	3	5	2	3
Hydrostatic Pressure	4	17	26	44	68	2	3	2	3
Hydrostatic Pressure	12	4	6	8	12	46	71	7	11
Hydrostatic Pressure	14	6	9	16	25	37	57	6	9
Archimedes' Law	3	22	34	36	55	3	5	4	6
Archimedes' Law	9	6	9	39	60	16	25	4	6
Surface Tension	7	4	6	28	43	16	25	17	26
Surface Tension	10	9	14	10	15	43	66	3	5
Surface Tension	11	4	6	16	25	42	65	3	5
Capillarity	6	41	63	10	15	12	18	2	3
Capillarity	8	33	51	16	25	14	22	2	3
Viscosity	2	48	74	14	22	2	3	1	2
Viscosity	16	37	57	13	20	13	20	2	3
Viscosity	17	44	68	17	26	3	5	1	2

Table 11: Results of student misconceptions identification on the static fluid chapter

Based on Table 11, a separate graph can be prepared to further specify the level of student misconceptions. The graph of student misconceptions regarding the static fluid chapter can be shown in Figure 2.

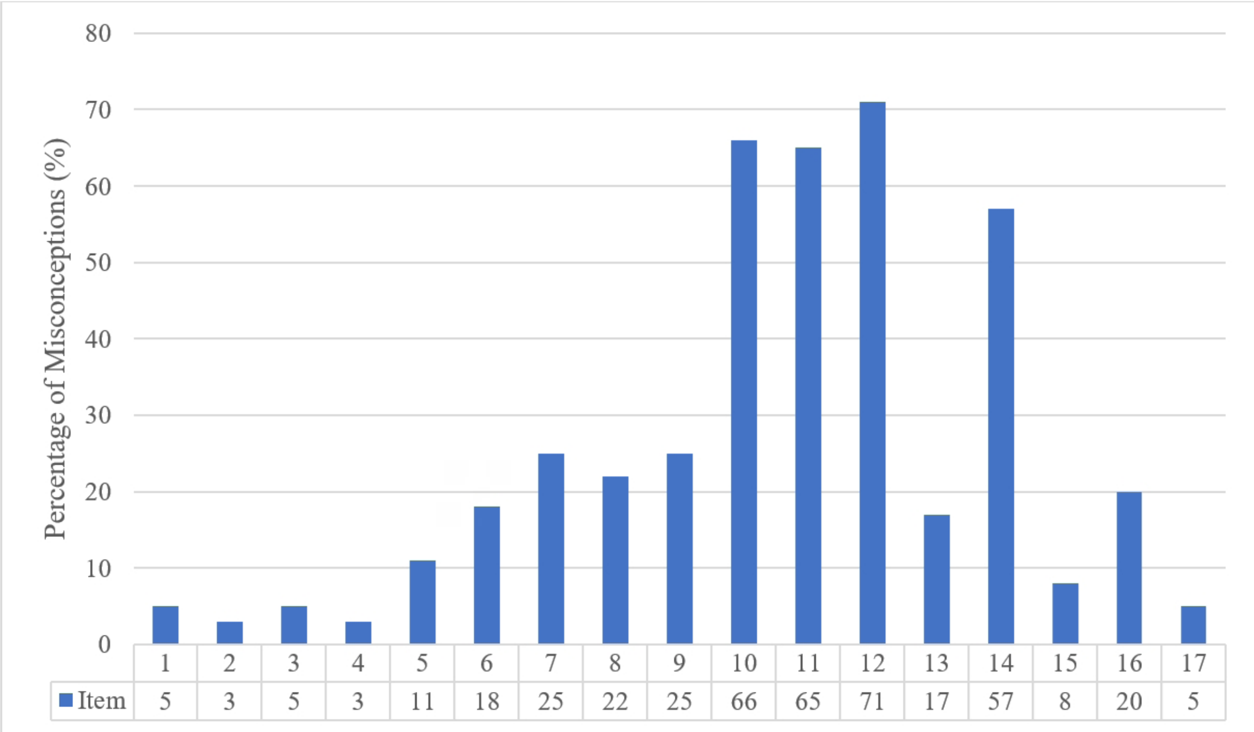

Figure 2: Percentage of student misconceptions on static fluids

Figure 2 shows that students had the most misconceptions on item 12, with 71% (46 students) exhibiting misconceptions. Question number 12 is an item related to the hydrostatic pressure sub-chapter. Apart from question 12, students had the most misconceptions in questions 10 and 11. These two questions are related to the sub-chapter on surface tension. Most students understand the concept in number 2, sub-chapter 'Viscosity', with 48 students (74% of the class). This means that most students' answers are correct and receive full points on question 2. Meanwhile, most students do not understand the concept in sub-chapter 7, surface tension: 17 students (26%). This means that 17 students who worked on number 7 scored 1.

DISCUSSION

Quality of four-tier diagnostic test instruments

The findings of this study demonstrate that the development and validation of the four-tier diagnostic test instrument, conducted through expert judgment and empirical testing, have successfully produced an assessment tool that generally meets the standards of diagnostic measurement. Expert validation ensured conceptual accuracy, while the subsequent Rasch-based analysis provided empirical evidence of item functioning. However, the detection of several items requiring revision or elimination indicates that diagnostic efficiency has not yet reached optimal levels. Inefficient items, such as item 5, which failed to meet the outfit MNSQ, ZTSD, and Pt Measure Correlation criteria simultaneously, burden the assessment process by generating noise rather than meaningful diagnostic information. This finding is consistent with Van Laar et al. (2018), who highlight that misfitting items reduce the efficiency of inferential decision-making and compromise researchers' responsibility to provide accurate diagnostic interpretations. The present study demonstrates that empirical validation using the Rasch model is not merely an analytical choice but an ethical responsibility to ensure that each item is fit for purpose in identifying misconceptions with precision and fairness.

In terms of reliability, both the limited and extensive trials produced person reliability, item reliability, and Cronbach's alpha values exceeding the minimum threshold of 0.60 recommended by Çebi and Reisoğlu (2023) and Sürücü and Maslakçı (2020), indicating that the instrument is sufficiently stable for classroom use. Reliability consistency indicates that the instrument can efficiently capture students' conceptual profiles without introducing unnecessary measurement error. However, the exceptionally high item reliability in the extensive trial (0.96) raises critical implications. Although high item reliability suggests strong internal coherence, it also indicates that the instrument may lack heterogeneity in item difficulty, thereby limiting the test's diagnostic responsibility to represent diverse conceptual challenges. This limitation suggests that future development must incorporate items targeting a broader spectrum of cognitive complexity to ensure that the assessment remains not only efficient in operation but also responsibly inclusive in representing the diversity of student reasoning patterns.

Regarding item difficulty and discriminating power, the Rasch analysis reveals that most items performed adequately. However, two items showed excessively great difficulty, and item 14 displayed weak discriminating power. Items that are too difficult reduce assessment efficiency because they fail to differentiate students at varying ability levels, thereby producing data that are uninformative for instructional decision-making. This aligns with Saidi and Siew (2019) and Kim et al. (2016), who warn that poorly discriminating items jeopardize educators' diagnostic responsibility to accurately identify where and why misconceptions occur. The extremely great difficulty of items 11 and 6 may stem from indicators or stimuli misaligned with students' prior knowledge, while item 14's low discrimination suggests problems with wording clarity or unintended cues. These problematic items must therefore be revised to ensure that the instrument fulfils its responsibility to generate fair, transparent, and actionable diagnostic information that teachers can use in targeted instructional planning.

When positioned within the broader landscape of existing literature, the results of this study confirm the alignment of the developed instrument with modern Rasch-based measurement principles and its feasibility as a diagnostic tool in physics education, particularly for the static fluid chapter. Nevertheless, the strengths reported do not absolve researchers from the ongoing responsibility of iterative refinement. Continuous revision cycles comprising expert review, limited trials, Rasch calibration, and targeted item reconstruction are essential for maintaining diagnostic efficiency and accountability. Such cycles ensure that the instrument not only identifies misconceptions accurately but also supports teachers in designing interventions that are both instructionally effective and ethically responsible in addressing student learning needs. In practical classroom contexts, this diagnostic instrument can serve as a crucial evaluative tool for identifying misconceptions among grade XI students. Through its four-tier structure comprising content response, confidence rating, reasoning selection, and reasoning confidence, teachers can pinpoint misconceptions at a more granular level. This enables them to act responsibly by providing more in-depth, targeted instructional explanations. Teachers are encouraged to integrate four-tier diagnostic tests into formative assessment practices to increase assessment efficiency and improve instructional responsiveness. Future research should also investigate instructional designs tailored to specific misconception profiles, ensuring that responses to diagnostic findings are pedagogically responsible and evidence-based.

Additionally, comparative studies examining the diagnostic efficiency of four-tier tests versus traditional one-, two-, or three-tier tests are needed to determine the extent to which the added complexity of the four-tier structure truly enhances diagnostic accuracy. Such comparative analyses are essential for determining whether the increased effort required in developing and administering four-tier instruments is justified by correspondingly improved diagnostic outcomes, an important consideration in balancing educational efficiency and assessment responsibility. The Rasch analysis conducted in this study used the Winsteps application with a sample drawn from a single MAN in Bantul, which may limit generalizability. Furthermore, the instrument currently focuses solely on the static fluid chapter. Thus, future studies should expand the instrument to other physics domains to evaluate its broader applicability and to ensure responsible advancement of diagnostic tools across the physics curriculum.

Identify student misconceptions in the static fluids chapter

The findings of this study reveal a multidimensional pattern of students' conceptual mastery, partial comprehension, and deeply rooted misconceptions across key static fluid subtopics: hydrostatic pressure, density, surface tension, viscosity, and capillarity. These patterns reaffirm longstanding evidence in physics education that students frequently employ intuitive, experience-based reasoning rather than mechanistic scientific principles when interpreting fluid phenomena. However, the present findings extend earlier scholarship by demonstrating that students' confidence levels do not necessarily correlate with conceptual accuracy, raising critical questions about pedagogical responsibility in interpreting student confidence as a proxy for understanding. For example, the exceptionally high misconception rate in Question 12, where 71% of students incorrectly attributed the function of a hanging infusion bottle to capillary action, parallels the conceptual conflation documented by Li et al. (2020) and Liu and Li (2019). Yet this study adds nuance: many students expressed *high confidence in incorrect answers*, a signal that their reasoning frameworks are both robust and systematically flawed. This misalignment highlights a responsibility issue: teachers cannot rely on correctness or confidence alone as indicators of learning. Instead, instructional design must incorporate explicit mechanisms to probe underlying reasoning and prevent false certainty from propagating through subsequent learning experiences.

From an efficiency perspective, diagnostic instruments must therefore capture not only answer accuracy but also reasoning quality, enabling teachers to allocate instructional time more strategically to high-risk misconceptions. The correct scientific explanation of fluid flow driven by a pressure difference, as stated by Deiters and Kraska (2023) and Levy et al. (2021), further underscores the need for learning sequences that contrast similar phenomena while foregrounding the governing variables and mathematical relationships, thereby improving conceptual differentiation without increasing instructional load. A similar pattern emerges in Question 4, where students demonstrated partial understanding of hydrostatic pressure in real-world diving contexts. Consistent with Domínguez et al. (2022) and Raissi et al. (2020), students recalled formulas but failed to integrate density, depth, and gravitational acceleration into coherent physical reasoning. This indicates a *systemic pedagogical gap,* the insufficient bridging of theoretical representations and applied contexts, which compromises the efficiency of instruction, as time spent teaching formulas yields limited conceptual payoff. To increase instructional efficiency and uphold pedagogical accountability, educators must adopt simulation-based visualizations or hands-on experiments, enabling students to concretely experience pressure gradients rather than relying on symbolic abstractions.

Misconceptions about density (Question 13) continue this theme. With 28% of students demonstrating either partial or no understanding, the findings corroborate difficulties reported by Kiray and Simsek (2021) and Zenger and Bitzenbauer (2022). Errors such as predicting that low-

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density objects would sink in high-density fluids reflect a failure to coordinate relative densities, indicating that rule-memorization approaches are pedagogically inefficient and ethically questionable when they produce superficial recall rather than conceptual insight. The strength of this diagnostic pattern lies in its ability to pinpoint specific misconceptions, allowing teachers to take targeted, responsible action. However, the instrument alone cannot reveal the cognitive origins of these misconceptions, necessitating qualitative follow-up research such as think-aloud protocols. Such approaches would enhance the efficiency and accountability of future diagnostic cycles by clarifying the reasoning errors that assessments cannot directly capture. Surface tension misconceptions (Questions 7 and 10) reveal similar instructional vulnerabilities. Students' beliefs that hot or soapy water has higher surface tension contradict molecular-level explanations documented by Nguyen et al. (2020), Tang et al. (2020), and Tsompou and Kocherbitov (2022).

These misconceptions highlight the lack of molecular macroscopic linkages in current teaching practices, a form of *curricular inefficiency* where students struggle to generalize concepts because instruction does not sufficiently develop explanatory depth. Integrating molecular dynamics simulations or inquiry-based experimentation is therefore both an efficient and responsible pedagogical alternative, providing high-yield conceptual clarity through experiential engagement rather than additional lecturing time. The findings for Question 9 on Archimedes' Principle echo patterns reported by Naylor and Tsai (2022) and Noxaïc and Fadel (2022): students memorize formulas but fail to internalize that the buoyant force equals the weight of the displaced fluid. Low confidence and fragmented conceptual frameworks indicate unstable knowledge structures that undermine learning progression. Addressing this issue requires repeated exposure to diverse problem variations and structured opportunities for students to articulate their reasoning, an efficient strategy for reinforcing conceptual stability across contexts while ensuring responsible instructional practice.

In contrast, the high conceptual performance in viscosity (Question 2) and capillarity (Question 6) offers essential insights into instructional efficiency. Consistent with findings by Kaptay (2021), Shafiei et al. (2023), and Gupta et al. (2023), these topics benefit from highly observable and manipulable phenomena, demonstrating that conceptual understanding improves when teaching practices integrate physical intuition, observation, and inquiry. These results reinforce the need for physics instruction that prioritizes experiential engagement over purely representational approaches, thereby supporting both efficient learning progression and equitable access to conceptual understanding for diverse learners. Taken together, the findings suggest that students understand fluid concepts more effectively when instruction is grounded in concrete, observable, and intuitive experiences. However, they struggle when concepts require abstraction or differentiation among superficially similar principles. This observation carries significant implications for curricular efficiency and teacher responsibility: physics education must integrate conceptual, experimental, and representational domains more coherently so that students can internalize distinctions among related fluid concepts without additional cognitive burden.

Methodologically, while the four-tier diagnostic test provides invaluable information for identifying misconceptions, its multiple-choice format limits insight into students' reasoning pathways. To enhance *assessment responsibility*, future research should complement diagnostic tests with interviews, classroom observations, or open-ended tasks that more explicitly reveal cognitive processes. Additional studies comparing the efficiency and diagnostic accuracy of four-tier tests against one-, two-, and three-tier formats would also clarify whether the extra layers of confidence judgment truly improve conceptual detection or increase assessment load without proportional benefit. Finally, the study's context is limited to a single MAN in Bantul, and the materials are restricted to static fluids, which limits generalizability. Responsible future research should expand sample diversity and extend the diagnostic instrument to additional physics topics to ensure broader applicability. Nevertheless, the current findings already serve as a powerful evaluative tool for teachers, enabling targeted intervention and more efficient allocation of instructional resources based on empirically verified patterns of student reasoning.

CONCLUSIONS

Three key conclusions can be drawn from the research results and discussion presented in this study. The first conclusion is that the four-tier diagnostic test instrument includes a grid of test questions, work instructions, an answer key, an answer sheet, and scoring guidelines. The test question structure consists of four levels, including questions with one answer key and three distractors, level of confidence in the answer, reason options, and level of confidence in the reason. The second conclusion is that the four-tier diagnostic test instrument developed has met validity standards, allowing it to be tested on research subjects. The results of the empirical validity analysis of trials limited to 18 items indicate that 17 items have validity, while one item falls into an invalid category. The reliability analysis results on the limited and extensive trials produced the same person reliability coefficient and Cronbach's alpha coefficients. However, the item reliability coefficient from the extensive trial was greater than that from the limited trial because one empirically invalid question item had been removed. Additionally, an analysis of the questions' difficulty levels revealed that two were very difficult, nine were difficult, and nine were moderate. Evaluation of the discriminating power of the questions revealed that 19 questions had good discriminating power, while 1 had poor discriminating power. The third conclusion, based on a four-tier diagnostic test instrument, is that students' misconceptions most often occur in the hydrostatic pressure sub-chapter (71%) and in surface tension (66%). The four-tier diagnostic test instrument has proven effective in categorizing students into four categories: understanding the concept, partially understanding, misconceptions, and not understanding the concept. This is confirmed by extensive trials, which show different values for each indicator across the six categories.

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Full research paper

UTILIZING ICT-BASED LEARNING RESOURCES TO ENHANCE CREATIVITY AND INNOVATION FOR PRE-SERVICE STUDENTS OF VOCATIONAL EDUCATION

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ABSTRACT

In today's vocational education, preparing prospective vocational teachers requires developing innovative, creative thinking that strengthens pedagogical competence and classroom management. These abilities help address the complexity of modern vocational classes and support a positive, engaging learning environment. This study examines how prospective vocational teachers manage ICT-based learning resources to encourage creativity and innovation in their professional practice. A quantitative approach was applied with 178 participants, evenly assigned to a control group and an experimental group. The experimental group used ICT-based learning tools, including interactive multimedia and various digital technologies. Results showed that participants who effectively used ICT resources achieved higher levels of creative and innovative thinking. The experimental group's N-Gain score reached 0.756, compared with only 0.049 in the control group. This significant difference strongly suggests that appropriate use and management of ICT learning resources can help future vocational teachers create more productive classroom conditions and strengthen their entrepreneurial abilities. The notable learning gains also demonstrate that ICT-based multimedia improves instructional effectiveness compared with traditional methods. Overall, the findings clearly highlight that future TVET educators who master digital learning resources will be better prepared for teaching demands and the challenges of contemporary TVET.

KEYWORDS

Classroom management, creative thinking, ICT, innovative skills, instructional efficiency, pre-service vocational teachers

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Highlights

- *ICT-based learning resources significantly enhance creativity and innovation among pre-service teachers.*
- *Interactive multimedia improves digital pedagogy skills for vocational teacher education.*
- *Proper management of digital tools boosts instructional efficiency in vocational learning environments.*
- *Structured ICT training is essential for preparing future vocational educators for Industry 4.0.*

INTRODUCTION

Creative and innovative thinking skills are essential for success in an increasingly competitive business world. In vocational education, particularly in vocational high schools (SMK), these skills play a crucial role in preparing students to meet industry demands and entrepreneurial challenges. Creativity and innovation enable individuals to generate new ideas and solve problems effectively, serving as key competencies in the modern workforce (Dewanti, 2022). However, studies indicate that many vocational education programs struggle to equip students with these critical skills, as the curriculum often emphasizes technical expertise over creative problem-solving. One study by Muharam and Afrilia highlights that many vocational education programs concentrate heavily on technical skills, often at the expense of fostering creative and critical thinking skills necessary for students to adapt in dynamic work environments (Muharam and Afrilia, 2024). This claim aligns with Guo's findings, which discuss the challenges in vocational education systems, specifically noting that an overemphasis on skill-based training leads to a neglect of essential problem-solving and creative competencies among graduates (Guo, 2023). Furthermore, Groeneveld et al. (2021) argue that combining technical knowledge with creativity is essential in software engineering, asserting that outstanding performance in complex fields requires more than technical aptitude; it demands innovative thinking to tackle intricate challenges.

Moreover, Yao and Shi (2024) indicate that while digital transformation and modern pedagogical strategies are likely to enhance teaching methodologies within vocational education, they also uncover gaps in resource availability to effectively implement these strategies, which might hinder the integration of creative problem-solving approaches into traditional curricula. The integration of soft skills, encompassing creativity and critical thinking, is emphasized in a study on the pedagogical challenges faced by vocational educators (Nkwadipo and Rabaza, 2021). This limitation in pedagogical focus hinders students' ability to develop innovative solutions, adapt to evolving industry requirements, and compete in the global job market (Ummah et al., 2019; Istiq'faroh et al., 2020).

Some studies highlight the interconnectedness of creativity, innovation, and entrepreneurship in vocational education, emphasizing that these elements are crucial not only for workforce readiness but also for cultivating an entrepreneurial mindset (Tambunan et al., 2021). Research suggests that teacher creativity enhances entrepreneurship education and student innovation, while structured entrepreneurship spaces in vocational institutions stimulate entrepreneurial intentions (Machali et al., 2021). However, while entrepreneurial education fosters motivation and intention, its direct influence on creativity remains ambiguous, indicating the need for more technology-driven pedagogical approaches (Paliwal et al., 2022). Self-efficacy and attitude significantly mediate the link between creativity and entrepreneurial intentions, suggesting that psychological factors shape vocational students' ability to innovate (Niu et al., 2022). Additionally, integrating digital tools into entrepreneurship education nurtures an entrepreneurial mindset, inspiration, and self-efficacy, further driving students toward innovation (Li et al., 2023). Institutions like community colleges contribute significantly to the development of innovation and creativity skills, particularly in vocational settings, while specialized fields such as sports entrepreneurship showcase how creativity and innovation drive industry transformation (Abusamra, 2022). Given these insights, leveraging technology-based entrepreneurial education is essential for equipping vocational students with the adaptive and problem-solving skills necessary to navigate the evolving entrepreneurial and industrial landscape.

Meanwhile, technology serves as a powerful tool in enhancing learning experiences and fostering innovation in vocational education (Mahmudah and Santosa, 2021). The integration of ICT-based learning resources, such as interactive simulations, e-learning modules, and cloud-based platforms, ensures that vocational education remains engaging, industry-relevant, and skill-focused (Durmus and Dağlı, 2017; Kharismaputra et al., 2020). Pre-service vocational teachers (PPG students) must develop technological and pedagogical competencies to effectively implement digital instructional strategies (Riyanda et al., 2025). Technological and pedagogical competencies enable pre-service vocational teachers to design adaptive, innovative learning environments that meet Industry 4.0 demands, such as integrating automation, digital tools, and data-driven instruction. Despite the growing digitization of education, many vocational teacher-training programs lack a systematic approach to integrating digital tools effectively (Redmond and Lock, 2019).

Despite its potential, integrating technology into vocational teacher education faces significant challenges. Research highlights limited access to digital resources, insufficient training, and a lack of structured guidance as major barriers to technology adoption (Mahmudah and Santosa, 2021). Moreover, traditional vocational teacher-training programs still prioritize theoretical instruction over practical ICT integration, resulting in gaps in digital literacy and pedagogical adaptability among pre-service teachers (Durmus and Dağlı, 2017; Kharismaputra et al., 2020). The era of Industry 4.0 increasingly recognizes the urgency of developing digital competence for prospective vocational teachers as a fundamental requirement. Studies emphasize that pre-service vocational teachers must acquire multidisciplinary digital competencies to effectively integrate technology into vocational education (Roll and Ifenthaler, 2021). However, significant gaps in digital skills persist among vocational educators, particularly in their ability to implement pedagogical technological knowledge effectively (Moreno-Guerrero et al., 2021). Several factors influence the development of digital competence, including attitudes toward technology, curriculum integration, and the specific requirements of teaching vocational subjects (Mulyanti et al., 2024).

Despite the crucial role of teacher educators in fostering digital competence among pre-service teachers, they themselves face challenges in fully integrating digital pedagogy into teacher training programs (Lindfors et al., 2021). Research underscores the urgent need to reform pre-service teacher curricula to systematically integrate the development of digital competence into teacher education (Tomczyk, 2024). Moreover, early-career teachers' ability to apply digital pedagogy is significantly shaped by institutional culture, access to resources, and the availability of support systems that sustain continuous digital skill development (Masoumi and Noroozi, 2023). Given these challenges, vocational teacher training programs must prioritize the structured development of pedagogical technological knowledge, ensuring that digital competency is not only an individual responsibility but also an institutional commitment to equipping future educators with the skills necessary for technology-driven vocational education. While existing studies have extensively explored the benefits of interactive multimedia in improving student engagement and learning outcomes, limited attention has been given to how pre-service vocational teachers develop the ability to manage and implement ICT-based instructional strategies effectively. This creates a significant research gap in understanding how teacher training programs can better prepare pre-service educators to integrate technology into vocational learning environments.

This study explores the role of interactive multimedia in entrepreneurship education for pre-service vocational teachers. Specifically, it seeks to: (1) assess how interactive multimedia enhances creativity and innovation skills, (2) evaluate competencies in managing and implementing ICT-based instructional strategies, and (3) determine the impact of structured digital pedagogy training on preparing pre-service vocational teachers for technology-driven vocational education. The findings aim to inform curriculum enhancements, promoting technology-driven instructional approaches that foster creativity, innovation, and industry-aligned teaching practices. In general, this paper will include a literature review, a theoretical framework, methods, research results, a discussion of the research findings, and conclusions, and end with a bibliography of references from relevant research to justify or refute the research findings.

LITERATURE REVIEW

The role of ICT-based learning resources in vocational teacher education

Technology has become an integral part of modern education, particularly in vocational teacher training, where educators must be prepared to integrate ICT-based learning resources into their teaching practices. Studies indicate that interactive multimedia, simulations, and digital learning platforms enhance student engagement, improve conceptual understanding, and support hands-on learning experiences (Durmus and Dağlı, 2017; Kharismaputra et al., 2020). Effective use of these technologies equips pre-service teachers with the skills necessary to create student-centered, industry-relevant learning environments (Mahmudah and Santosa, 2021).

Despite its potential benefits, integrating ICT into vocational teacher education is difficult. Pre-service teachers face challenges such as limited technical infrastructure, structured instruction, and digital literacy (Riyanda et al., 2025; Redmond and Lock, 2019). According to Kaminskienė, Järvelä, and Lehtinen (2022), the Technological Pedagogical Vocational Knowledge framework can help integrate ICT into vocational teacher education programs, preparing future educators to effectively manage and optimize digital teaching tools. Studies show that while many institutions offer ICT facilities, teacher education rarely uses them (Pozas and Letzel, 2023). Another study shows that two key factors, teachers' internal perceptions and external campus support, directly motivate vocational college teachers in China to teach with ICT. Among all variables, "ICT use intention" is the most critical bridge: it absorbs the positive influence from teachers' perceptions and then transmits it into actual classroom actions (Yang et al. 2023). In Indonesia, many vocational teacher education programs lack digital infrastructure, ICT integration, pedagogical training, and institutional support for technology-driven instruction (Budiarto et al., 2025). Although the government promotes digital transformation in education, the gap between policy and practice remains large, suggesting the need for structured training programs to equip pre-service vocational teachers with digital and pedagogical skills to integrate ICT into vocational learning environments.

Digital competence of prospective vocational teachers

The development of Pedagogical Technological Knowledge is essential for prospective vocational teachers to effectively integrate technology into their teaching practices. Recent studies highlight the positive impact of TPACK-based training programs on pre-service teachers' perceptions of technology integration (Diamah et al., 2022) and on classroom management in technology-enriched environments (Saritepeci, 2022). Effective technology integration fosters student engagement and academic achievement, particularly when combined with learner-centered pedagogies (Aljehani, 2024). Additionally, factors such as self-efficacy, interest, and motivational beliefs significantly influence teachers' ability to adopt technology in instruction (Istiningsih, 2022). Institutional support further strengthens technology adoption, impacting both teacher performance and student learning outcomes (Panakaje et al., 2024).

However, developing ICT competencies among prospective vocational teachers faces multiple challenges. Limited time and resources in vocational schools (Vilppola et al., 2022), inadequate infrastructure, and insufficient exposure to emerging technologies hinder effective technology adoption. Additionally, the attitudes and digital competencies of teacher educators play a significant role in shaping ICT integration within vocational teacher training programs (Divayana et al. 2021). Studies indicate that pre-service teachers' self-perceived competency and attitudes strongly predict their future use of ICT in teaching (Pozas and Letzel, 2023). The rapid evolution of technology demands continuous adaptation, yet vocational education still suffers from low ICT adoption across various instructional components (Hassan et al., 2021). Addressing these barriers is crucial to ensure that vocational educators develop comprehensive digital competencies that align with the demands of Industry 4.0. Thus, structured digital pedagogy training, institutional investment in ICT infrastructure, and targeted professional development programs are essential to prepare future vocational teachers for technology-driven educational environments.

Creativity and innovation as core competencies for pre-service vocational teachers

The 21st-century education framework emphasizes the development of creativity, innovation, critical thinking, collaboration, and communication as essential competencies for preparing vocational educators to meet industry demands (Julaihi and Hamdan, 2020). Pre-service vocational teachers must cultivate creativity and innovation skills to develop engaging instructional approaches that foster entrepreneurial mindsets and problem-solving abilities (Tambunan et al., 2021; Zhang and Yu, 2022). Research suggests that interactive multimedia significantly enhances students' motivation, improves their creative thinking abilities, and fosters innovation-driven learning environments (Gunawardhana and Palaniappan, 2016; Howorth et al., 2012).

However, vocational teacher education programs often lack a strong emphasis on creativity and innovation, focusing more on technical expertise than adaptive teaching strategies (Machmud et al., 2021; Boyles, 2012). This training gap leaves pre-service teachers struggling to design and implement technology-driven instructional approaches, limiting student engagement and overall learning outcomes (Mirzanti et al., 2015; Rejekiningsih et al., 2022). Recent studies advocate for curriculum reforms that integrate experiential learning, digital instructional design, and creativity-based teaching methodologies to better prepare pre-service teachers for modern educational challenges (Noguera et al., 2024; Göltl et al., 2024). By equipping future educators to manage and use digital learning resources effectively, vocational teacher education can ensure graduates are well-prepared to foster innovation, adaptability, and digital literacy in vocational learning environments. The incorporation of ICT-based instructional strategies, entrepreneurship education, and multimedia technology into teacher training programs can bridge the gap between traditional pedagogy and the digital education landscape, ultimately enhancing teaching effectiveness and student success (Ismail and Buang, 2019; Sefriani et al., 2020).

Theoretical frameworks

Guided by the Technological, Pedagogical, and Vocational Knowledge framework, this study posits that interactive multimedia serves as a contextual trigger, converting vocational content knowledge into creative, innovative pedagogical actions among pre-service teachers. This framework argues that effective ICT integration requires the interplay of technological fluency, pedagogical flexibility, and authentic vocational context, uniquely satisfied by entrepreneurship-oriented interactive multimedia (Kaminskienė et al., 2022). Technological-Pedagogical-Vocational Knowledge posits that pre-service vocational teachers must simultaneously command technological, pedagogical, and vocational content knowledge to transform ICT-based resources, such as interactive multimedia, into creativity-enhancing and innovation-driving learning experiences. Empirical evidence indicates that when teachers possess this robust framework, they are more likely to design student-centered, industry-relevant activities that foster entrepreneurial mindsets (Mahmudah and Santosa, 2021; Saritepeci, 2022). Conversely, deficits in any Technological, Pedagogical, and Vocational Knowledge dimension constrain the enactment of higher-order 4Cs skills, particularly creativity and innovation (Julaihi and Hamdan, 2020). Consequently, this theorizes that structured engagement with such multimedia cultivates Technological Pedagogical Vocational Knowledge competence, which in turn manifests as observable creativity (idea fluency, originality) and instructional innovation (risk-taking, collaborative design) within entrepreneurship lessons. This study aims to address this gap by analyzing the effectiveness of structured digital pedagogy training and the role of multimedia tools in enhancing teaching competencies among pre-service vocational teachers. By doing so, this research contributes to the development of vocational teacher education curricula, ensuring that graduates are equipped with the necessary skills to implement technology-driven instructional approaches that align with industry and educational demands.

MATERIALS AND METHODS

Research design and participant

This study employed a quantitative approach to assess the effectiveness of ICT-based learning resources in enhancing creativity and innovation skills among pre-service vocational teachers. A quasi-experimental design with cluster sampling was chosen because practical constraints, such as the existing class structure, made full randomization impossible. Furthermore, this design offers greater contextual relevance than a fully randomized experiment, though it may introduce selection bias (Patel and Patel, 2019). The control group followed traditional entrepreneurship education, while the experimental group integrated interactive multimedia, simulations, and digital platforms.

This study employed a quasi-experimental design, with participants assigned to either a control or an experimental group via a cluster-randomized design (Sutrisni et al., 2022). A total of 178 students from one of the public universities in Surakarta, Indonesia, were randomly assigned to the control and experimental groups (Table 1).

Group	Pre Test	Treatment	Post Test
Experiment	O	X1	O
Control	O	-	O

Table 1: Pre–Post Control Group Design

Table 1 compares the experimental group, which used ICT-based learning resources, with the control group that employed conventional media such as PowerPoint presentations and webpages. The experimental group integrated interactive multimedia, animated videos, and simulations developed with Articulate Storyline into entrepreneurship learning sessions on the Moodle e-learning platform. Conducted over two weeks in blended (online and offline) formats, the six 90-minute sessions centered on business plan development and entrepreneurial case studies. These implementation details were incorporated into the data analysis and discussion to ensure that the observed effects on creativity and innovation were interpreted within their instructional context. A quasi-experimental design with cluster sampling was used to select 178 pre-service vocational teachers (89 per group) from a public university in Indonesia (Sutrisni et al., 2022). This design was considered appropriate given the pre-existing class structures, which made random assignment impractical, while still allowing for meaningful comparisons across equivalent groups. The inclusion criteria targeted students enrolled in teacher education programs with prior coursework in instructional media, ensuring relevance to ICT-based pedagogical contexts. This approach maintained representativeness among vocational teacher candidates and enabled a valid assessment of ICT integration's effectiveness in fostering creativity, innovation, and pedagogical adaptability.

Data collection instruments and techniques

A two-stage examination examined how ICT-based interactive multimedia affected pre-service vocational teachers' creativity and innovation. Participants took the pre-test from May 24–28, 2021, to assess their creativity and innovation skills. The experimental group was taught using interactive multimedia and digital learning tools, while the control group used traditional approaches. The post-test was held June 7–11, 2021, to evaluate creativity and innovative skills after this organized session. Pre- and post-test scores and questionnaire responses were used to assess the effectiveness of digital teaching strategies in fostering creativity and pedagogical adaptation among pre-service vocational instructors.

Instrument development

The Creativity-Innovation Skills Scale was developed through a three-phase adaptation of the scales by Faiziyah et al. (2020), Indrawati (2021), and Koyuncuoglu (2021). First, items were translated–back-translated (English–Indonesian) by two certified translators; discrepancies were resolved by a panel of three vocational-education experts. Second, the Item-Level Content Validity Index was used to assess content validity. Three external experts (two TVET lecturers and one educational-technology professor) scored each of the 30 initial topics on a 4-point relevance scale. Topics with I-CVI < 0.78 were eliminated or reworded, leaving 21 items (average CVI = 0.91). Third, 30 non-mainstream pre-service vocational teachers were pilot-tested. Table 2a shows that all dimension *Cronbach's alpha* values are above 0.70 (Kaplan, 2023). Participants used a 5-point Likert scale with 1 = Strongly Disagree and 5 = Strongly Agree. Finally, the measure comprises 21 items across 7 dimensions that align with the 4Cs and the entrepreneurial literature.

The assessment instrument, detailed in Table 2, included seven key indicators to evaluate the effective management, integration, and application of ICT-based learning resources.

Component	Item	Indicator	Instrument Type	α (*n* = 30)	I-CVI
Fluency	2	Generating Any Ideas	Likert Scale 1–5	0.82	0.93
	2	Idea Differentiation	Likert Scale 1–5	0.82	0.90
Flexibility	3	Ability to adapt to situations	Likert Scale 1–5	0.79	0.88
Originality	1	Generate new ideas	Likert Scale 1–5	0.85	0.95
	2	Out of the box thinking	Likert Scale 1–5	0.85	0.92
Elaboration	1	Develop details of ideas	Likert Scale 1–5	0.80	0.91
	3	Detailed explanation	Likert Scale 1–5	0.80	0.89
Risk Taking	2	Ability to take risks	Likert Scale 1–5	0.78	0.87
	1	Facing challenges	Likert Scale 1–5	0.78	0.86
Leadership	2	Decision-making	Likert Scale 1–5	0.83	0.93
	2	Inspirational	Likert Scale 1–5	0.83	0.92
Collaboration	3	Ability to collaborate with a team	Likert Scale 1–5	0.81	0.91
	2	Communicate ideas and ideas effectively	Likert Scale 1–5	0.81	0.90

Table 2: Outline of the Instrument on Creativity and Innovation Skills (Adapted from Research Faiziyah et al. (2020), Indrawati (2021), Koyuncuoglu (2021))

Data analysis technique

The data analysis technique employs a hypothesis-testing approach using an independent t-test (Nor et al., 2022). The purpose of the hypothesis testing was to determine whether multimedia interaction has a substantial impact on pre-service teachers' creativity and innovation skills. The formulated hypothesis aimed to ascertain the outcome of the test decision.

H0 = Multimedia interactive has no significant effect on improving creative and innovation skills in entrepreneurship learning/subject.

H1 = Multimedia interaction has a significant effect on improving creative and innovative skills in entrepreneurship learning/subject.

SPSS 25 helped analyze experimental data using the Independent Sample t-test. To assess the extent to which ICT-based learning tools improved pre-service vocational instructors' creativity and innovation, the *N-Gain Score* was calculated. Table 3 shows that *N-Gain* scores vary from 0.3 to 0.7 (Meltzer, 2002). This study examined how integrating digital resources into teacher preparation programs improves pedagogical innovation and technology management skills among future vocational educators.

$g > 0.7$	High Increase
$0.3 \leq g \leq 0.7$	Medium Increase
$g < 0.3$	Low Increase

Table 3: *N-Gain* Category (source: Meltzer (2002))

RESULTS

Implementation of data collection and prerequisite test results

The assessment was conducted online, with students utilizing various resources and materials. Both the experimental and control groups participated in a pre-test and a post-test. The pre-test was administered from May 24th to May 28th, 2021, and included questionnaires and project-based assessments. From June 7th to June 11th, 2021, different teaching methods were implemented for each group to evaluate and compare improvements in their scores. The experimental group was exposed to interactive multimedia, while the control group used conventional media such as PowerPoint presentations and websites.

Pre-service teacher students were selected and divided into experimental and control groups, each with 89 students. The test results served as a benchmark for measuring the study's success. The control group achieved a pre-test mean score of 55.6, while the experimental group had a slightly higher pre-test mean score of 58.8. After the intervention, the post-test scores increased to 62.6 in the control group and to 91.78 in the experimental group, a significant difference. This substantial improvement in the experimental group's scores highlights the effectiveness of interactive multimedia in enhancing learning outcomes compared to traditional methods.

However, to draw a conclusion, it is crucial to conduct an effectiveness test to assess the enhancement in creative and innovation skills and determine the extent of multimedia's influence on entrepreneurship learning. Table 4 presents the illustration of the pre- and post–test comparison.

Pre-Test	55.6	55.8	0.02
Post-Test	62.6	91.78	29.18

Table 4: Comparison of the mean scores of pre-service teacher students

The effectiveness test was done to evaluate how multimedia affects the learning of creativity and innovation skills. Before the test, the data must undergo prerequisite tests such as normality and uniformity tests. If the data follows a normal distribution, validity tests can be done. For this study, the Kolmogorov-Smirnov test was used to analyze the results using SPSS 25. The results of the Kolmogorov-Smirnov statistics in the experimental and control groups are presented in Table 4. The significance values for both groups are 0.058 and 0.053, respectively. It is worth noting that both groups have normally distributed data, as indicated by the significance values being greater than 0.05. This allows continued testing of the data's homogeneity. Table 5 presents the results of the SPSS analysis.

	Class	Kolmogorov-Smirnov			Normality
		Statistic	*N*	*p*	
Creativity and Innovation Skills	Experiment	.248	89	.058	Normal
	Control	.175	89	.053	Normal

Table 5: Test of normality

Levene's statistical test was used to compare population variances in the product effectiveness test. Homogeneity is determined by the significance level, which should be above 0.05 ($p > 0.05$). If the significance level is greater than 0.05, the variances are homogeneous, allowing for additional hypothesis testing. Table 6 below shows the homogeneity test results. The p value is 0.727, which is greater than the significance level of 0.05 ($0.727 > 0.05$), indicating that the data variance is homogeneous. Meeting the homogeneity criteria allows us to proceed with a hypothesis test to assess the impact of multimedia interaction on improving creative and innovative skills in entrepreneurship education.

Levene Statistic	*df*1	*df*2	*p*
0.122	1	178	.727

Table 6: Test of homogeneity

The influence of interactive multimedia on pre-service teachers' creativity and innovation skills

The statistical analysis was conducted to assess the impact of interactive multimedia on the creative and innovation skills of pre-service vocational teachers. The independent-samples t-test was used in SPSS 25 to determine statistical significance. As shown in Table 7, a significance value (*p 2-tailed*) of < 0.001, which is below the 0.05 threshold, leads to the rejection of H0 and acceptance of H1. Additionally, the *t-value* (*tcount* = 33.891) exceeded the critical value (*ttable* = 1.6536, $df = 178$, $\alpha = 0.05$), further confirming a statistically significant effect. These results indicate that integrating interactive multimedia via smartphones into classroom activities substantially enhances creativity and innovation skills among pre-service vocational teachers in entrepreneurship education. The detailed statistical calculations are presented in Table 7.

	Value of *t*	Df	*p* (2-tailed)	Mean Difference	Standard Error Difference
Difference of means	33.891	178	< 0.001	32.98	0.97

Table 7: Independent sample test results

The upcoming assessment aims to evaluate the product's effectiveness in improving students' ability to innovate and be creative. To achieve this, the Gain Score will be used, along with test results from the analysis of both the control and experimental groups. According to the *N-Gain* calculation, the experimental group obtained an *N-Gain* score of 0.756, placing it in the 'High Increase' category. On the other hand, the control group's *N-Gain* test result of 0.049 is categorized as 'Low Increase' on the *N-Gain* scale. The efficacy test results indicate that multimedia effectively augments creative and innovative abilities in entrepreneurial education. Table 8 will present the statistical analysis.

Description	Experimental Group	Control Group
Average Score	91.8	58.8
N-Gain Score	0.756	0.049
Category	High Increase	Low Increase

Table 8: Gain score test results (*N-Gain*)

The findings indicate that integrating ICT-based learning resources is crucial for fostering creativity and innovation among pre-service vocational teachers. The significant difference in performance between the control and experimental groups underscores the impact of effective digital resource management on enhancing teaching competencies. Pre-service teachers who engage with interactive multimedia and technology-driven instructional methods demonstrate greater proficiency in designing and delivering creative and innovative lesson plans. In addition, the higher learning gains achieved by the experimental group suggest that ICT-based multimedia also supports greater instructional efficiency compared to conventional approaches.

DISCUSSIONS

The impact of interactive multimedia on teaching competencies in vocational teacher education

The effectiveness of interactive multimedia in vocational teacher education is increasingly recognized as a key factor in fostering creativity and innovation among pre-service vocational teachers. This study assesses its impact via pre- and post-test evaluations, indicating substantial enhancements in pedagogical competencies, especially in entrepreneurship education. The experimental group, which utilized ICT-based learning resources, outperformed the control group, confirming that integrating interactive multimedia enhances instructional effectiveness compared to conventional methods (Guo and Jia, 2016; Ma, 2021). Recent studies highlight the increasing importance of technology in vocational teacher education. Despite having ICT facilities, many institutions struggle to effectively utilize them due to technical, curricular, and capacity issues (Eyadat, 2023). In China, while multimedia technology enhances vocational education, low adoption of online resources remains a barrier (Wu, 2024). The TPVK framework supports ICT integration, and some people think it should be renamed TAWOCK to better align with vocational education (Rahmawati et al., 2021; Arifin et al., 2020). The situated digital VET model offers new insights into contextualizing digital resources for vocational teacher development (Dobricki et al., 2020). This finding corroborates TPACK's assertion that pedagogical transformation occurs only when technological, content, and contextual knowledge coalesce interactively.

Interactive multimedia and entrepreneurial skill development

The results of the *N-Gain* test show that the average test score for the multimedia group is significantly higher than that of the control group in improving pre-service teachers' entrepreneurial competencies. The study found that creating interactive multimedia applications based on local resources enhanced pre-service teachers' entrepreneurial mindsets. The study successfully demonstrated that interactive multimedia based on local resources could enhance pre-service teachers' entrepreneurial attitudes, with creativity as a key indicator closely associated with the creative abilities explored in this investigation (Rejekiningsih et al., 2022; Wiana et al., 2018).

Several studies on the use of multimedia also demonstrate positive outcomes, as researchers have found that its use enhances pre-service teachers' learning achievements, both cognitively, attitudinally, and skill-wise. Similarly, research on the implementation of interactive multimedia has been developed by various scholars (Sefriani et al., 2020). Data analysis has demonstrated the effectiveness of interactive multimedia tools in fostering entrepreneurial learning. These tools not only help pre-service teachers learn about entrepreneurship but also offer them many of the advantages of multimedia. Furthermore, several studies emphasize the importance of providing effective support for entrepreneurship education in schools, acknowledging the vital role that entrepreneurial skills play in the digital era (Robles and Rodríguez, 2015). Incorporating entrepreneurship material in the learning experience creates an environment that encourages innovation and creativity, as supported by various research findings (Maresch et al., 2016; Ghafar, 2020). Hence, educators must ensure the integration of ICT in the learning process. When effectively implemented, entrepreneurship education aligns perfectly with pre-service teachers' creative and innovative capabilities, thereby enhancing their learning outcomes (Guo and Jia, 2016; Vidanagama and Karunathilake, 2021).

The use of interactive multimedia has been proven effective in enhancing instructional quality and preparing pre-service vocational teachers for technology-integrated teaching (Komalasari and Rahmat, 2019; Aurum and Surjono, 2021). Multimedia that incorporates diverse learning models and educational approaches can be strategically designed to support teacher training programs, ensuring that future educators develop competence in managing and utilizing digital learning resources (Li and Ren, 2018). Integrating teaching methodologies with interactive media equips pre-service teachers with the skills needed to create engaging, student-centered learning environments. Research confirms that multimedia-based instructional strategies foster creativity and innovation in both face-to-face and digital learning settings, helping future educators understand how to keep students engaged and facilitate meaningful learning experiences (Ma, 2021; Heo and Toomey, 2020). Additionally, multimedia tools assist pre-service vocational teachers in simplifying abstract and conceptual topics, making them more tangible and easier to communicate effectively in vocational education (Çeken and Taşkın, 2022). Malik and Agarwal (2012) highlighted that multimedia-enhanced teaching methodologies empower educators by streamlining instructional delivery, enabling future vocational teachers to effectively convey complex content using digital tools. The multimedia intervention enabled pre-service vocational teachers to move from basic ICT literacy to creative-innovative pedagogical design. Thus, equipping them with digital pedagogical skills is essential to bridge the gap between conventional teaching methods and modern, technology-driven instructional approaches in vocational education.

Meanwhile, our research findings also show that the effect size (*N-Gain* = 0.756) exceeds the average found in Europe, as in studies by Roll and Ifenthaler (2021) (*N-Gain* = 0.42) and Göltl et al. (2024) (*N-Gain* = 0.51). These studies successfully demonstrated that entrepreneurially oriented, contextually interactive multimedia produce greater pedagogical improvements in developing countries. This superiority is due to (i) the authenticity of local resources that increase cognitive relevance, (ii) the equivalence of cluster sampling that minimizes intergroup variance, and (iii) the entrepreneurial domain that naturally rewards creative risk ideas.

Bridging digital competence gaps in pre-service vocational teacher education

Pre-service vocational teachers face persistent challenges in integrating technology, including limited access to digital tools, weak technical support, and minimal practical training. Many struggle to adapt interactive multimedia to vocational contexts, while insufficient digital pedagogy skills and limited exposure to tech-enhanced teaching hinder effective adoption. Although ICT facilities exist in many institutions, their use remains constrained by technical, curricular, and capacity-related barriers (Ohanu et al., 2024; Eyadat, 2023). Low adoption of online resources and a lack of structured digital literacy training are also key obstacles (Riyanda et al., 2025). Addressing these issues requires comprehensive digital literacy training, access to high-quality resources, and continuous mentorship to ensure pre-service teachers can confidently manage and apply technology to enhance vocational education outcomes. Preparing pre-service vocational teachers to integrate technology into instruction is essential to meet evolving industry demands. While this study demonstrates the potential of multimedia technology to enhance creativity and innovation in entrepreneurship education, its implementation remains constrained by institutional scope, varying technological proficiency, and limited digital resources. The success of such integration depends largely on curriculum design, institutional support, and teachers' adaptability in utilizing ICT tools. Therefore, future research should focus on developing systematic approaches within vocational teacher education programs to strengthen digital pedagogical competence and ensure sustainable technology integration in teaching practice.

However, the analysis of this research finding also has several limitations that need to be acknowledged. For example, the study was conducted in a single institutional setting, which may limit the generalizability of the findings to various vocational education contexts with varying technological infrastructures. Furthermore, the quasi-experimental design, while practical, introduces potential selection bias that could influence group differences. Finally, the focus on short-term outcomes meant that the long-term retention of creativity, innovation skills, and instructional efficacy related to multimedia was not measured. These limitations offer important directions for future research to develop a more comprehensive understanding of how ICT-based learning resources shape vocational teacher competencies.

CONCLUSION

This study highlights the pivotal role of interactive multimedia in enhancing digital competencies among pre-service vocational teachers, demonstrating its effectiveness in fostering creativity and innovation, both crucial to 21st-century vocational education. Structured ICT training is essential for preparing future educators with the skills required to design engaging, student-centered learning environments that meet Industry 4.0 demands. However, challenges such as limited access to digital tools, insufficient technical support, and varying levels of technological proficiency among pre-service teachers hinder effective ICT integration, underscoring the need for comprehensive digital literacy training and robust institutional support. The study's findings are constrained by its focus on a single institution and by variations in participants' prior technological skills, which may affect generalizability, underscoring the need for broader, longitudinal studies to assess sustained impacts. Vocational teacher education programs should prioritize curriculum enhancements that incorporate multimedia, e-learning platforms, and adaptive methodologies, supported by continuous mentorship to ensure sustainable technology adoption. Future research should investigate systematic approaches to strengthen digital pedagogical competence, expand sample diversity across institutions, and examine long-term strategies to enhance pre-service teachers' adaptability in technology-driven instruction, ensuring graduates are well-prepared to navigate evolving educational landscapes and drive pedagogical innovation.

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Full research paper

BOOSTING CREATIVE THINKING AND ENTREPRENEURIAL ATTITUDE IN MANADO HIGH SCHOOL STUDENTS: APPLYING SCRUM WITH ETNOCHEMISTRY CONTEXT IN GREEN CHEMISTRY

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ABSTRACT

Scrum is a framework that supports the development of various student skills, yet its application in chemistry learning within the Manado local cultural context remains rare. This study aimed to examine the effect of the scrum method, combined with ethnochemistry, on students' creative thinking skills and entrepreneurial attitudes in green chemistry. Using a quasi-experimental pretest-posttest control-group design, the study involved 110 senior high school students in Manado, divided into an experimental group (55 students) using Scrum with ethnochemistry and a control group (55 students) using conventional learning. Data were analyzed using MANOVA and paired sample *t*-tests. Results showed that the experimental group experienced significant improvements in creative thinking skills and entrepreneurial attitudes compared to the control group. However, the method's complexity posed challenges that affected its overall implementation. Despite these challenges, the Scrum method within the ethnochemistry context proved to have a positive influence on students' skills. Therefore, this method is recommended for broader application in schools to enhance students' creative and entrepreneurial competencies.

KEYWORDS

Creative thinking skills, entrepreneurial behavior, ethnochemistry, green chemistry, Scrum method

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Highlights

- *Scrum with an ethnochemistry context significantly improved students' creative thinking skills and entrepreneurial attitudes compared to the scientific approach.*
- *The experimental group achieved higher N-gain scores in creative thinking (43.49%) and entrepreneurial attitude (26.2%) than the control group.*
- *Scrum fostered collaboration, responsibility, and real-world problem solving through projects grounded in Manado's local culture.*
- *Despite implementation challenges due to method complexity, Scrum proved effective in enhancing key student competencies.*

INTRODUCTION

Education in the 21st century requires students to develop critical thinking, collaboration, communication, and creativity skills, enabling them to adapt and compete in the era of the Fourth Industrial Revolution (Chusni et al., 2020). A 21st-century student-centered learning environment with a personalized approach to learning and active engagement (Mohd & Shahbodin, 2015). This learning environment requires teachers to act as mentors who support each student's learning experience (Harriet Wambui Njui, 2018). However, the study by Muderawan et al. (2019) found that inappropriate learning methods are still being taught. This causes some students to feel bored (Palupi et al., 2018) and difficulties in learning subjects such as chemistry, which are considered abstract and confusing (Prayunisa & Mahariyanti, 2022). Therefore, chemical materials that are relevant to the surrounding environment are needed, such as green chemistry, which reduces the impact of harmful substances on humans and the environment (Mammino, 2019). An aspect that can enrich the perspective on green chemistry is to relate it to ethnochemistry, the system of people's knowledge of their surrounding environment and the reciprocal relationships that occur within a particular culture (Zidny et al., 2020). The use of ethnochemistrys, such as the use of "saguer" drinks in Manado, which can be processed into alcohol. Ethnochemistry in the classroom can help students understand the concept of chemistry in a cultural context (Fasasi, 2017). Through the study of ethnochemistry, students can continue to inherit cultural heritage, thereby maintaining the values and characteristics of a region. However, teaching that integrates local cultural values in Manado is still limited. Therefore, ethnochemistry research is needed using innovative methods to stimulate students' understanding of chemistry related to culture in Manado.

An interesting introduction to the Scrum method is that it helps the team work flexibly and collaboratively (Schwaber & Sutherland, 2020). The introduction of the scrum method into the learning process has yielded positive results, increasing student initiative and independence (Cook, 2017). Previous studies have demonstrated the potential of Scrum in educational settings, yet its application in chemistry learning, particularly within the ethnochemistry context, remains underexplored. This study addresses the gap identified by Fernandes et al. (2021), who explained that the use of the Scrum method in education remains very limited. That research on it is still exploratory. Therefore, the scrum method is expected not only to be an effective tool for dealing with the complexity of learning but also to develop students' creative thinking skills. Creative thinking among students is necessary to solve daily problems (Retnawati et al., 2018). However, students' creative thinking skills in Indonesia remain in short supply. Research reveals that students generally exhibit significant weaknesses across all aspects of creative thinking (Perdana et al., 2020). This is influenced by various factors, including environment and culture (Nakano and Weschsler, 2018). An entrepreneurial attitude is crucial in learning, enabling students to cultivate motivation and entrepreneurial spirit, thereby fostering independence and job creation (Kamaluddin, 2018). This is based on the low number of entrepreneurs in Indonesia (Indonesia, 2020), which leads to high unemployment and poverty rates (Statistik, 2023). This study examines the impact of the Scrum method on students' creative thinking skills and entrepreneurial attitudes in ethno-chemistry.

Ethno-chemistry in learning contexts

The term ethnoscience is referred to as "original science" or traditional "ecological knowledge", which includes knowledge possessed by indigenous peoples (Zidny et al., 2020). Ethnoscience is the study of community science related to cultural activities in daily life, which is inherited from generation to generation as local wisdom and includes elements of scientific knowledge (Sumarni et al., 2016). In this concept, knowledge is closely related and inseparable from local culture and traditions (Garcia et al., 2020).

The local tradition of the people in the city of Manado, North Sulawesi province, namely "captikus," which is the result of fermentation from the sap of palm trees (*Arenga pinnata Merr*), is generally used by the people of North Sulawesi for alcoholic beverages with an ethanol content of around 30-55%. Captikus drink from the results of redistillation can be used to make natural hand sanitizers from palm sap, which have been shown to reduce the number of bacterial colonies after use (Sari and Ariani, 2023). Additional ingredients can be mixed into hand sanitizer. Clove oil is one of the essential oils that can be added and functions as an antibacterial.

Figure 1: Alcoholic Beverage "Captikus"

Based on this perspective, ethnochemistry encompasses the chemistry of certain indigenous peoples or cultures that have distinct approaches to studying nature. The function of ethnoscience is to facilitate students' exploration of societal facts and phenomena, integrating them with scientific knowledge (Silvia Melyasari et al., 2018). Students have been connected to the culture of life and nature since birth, even before formal education. Ethnoscience that is rooted in students' lives is a form of contextual experience (Parmin & Fibriana, 2019).

Characteristics of learning that integrates ethnoscience according to (Sumarni, 2018), namely (I) incorporating elements of local culture into the learning process such as teaching materials, methods, and various learning media related to local culture into the material to be taught; (II) Students can collect and integrate newly acquired knowledge with known knowledge; (III) Meaningful knowledge occurs when students interact with old information and new information by expanding their knowledge. This process helps learners to broaden their understanding in a significant way.

Scrum methodology

Scrum is a traditional agile method that utilizes sprints and different types of meetings to solve problems during the software development process (Fawareh, Al-Qbelat, and Al-Refai, 2022). Scrum is a working method that helps people, teams, and organizations to generate value through adaptive solutions to complex problems (Schwaber & Sutherland, 2020). Scrum uses an iterative and incremental approach to optimize forecasts and control risks. This methodology involves teams that self-organize, divide roles, measure performance, and execute work cycles (de Melo Jr, 2019). Scrum consists of a group of people who collectively have the skills and expertise to do the job and share or acquire them as needed. The components of Scrum are roles, ceremonies, and artifacts (Schwaber & Sutherland, 2020):

1. Scrum teams use ceremonies to guide their routine activities.
2. Scrum teams use artifacts to visualize and manage the team's progress on the project, ensure transparency, and keep the team focused on the goal. Some of the artifacts used are (Schwaber & Sutherland, 2020):
   a) A product backlog consists of several items needed to achieve project objectives.
   b) The scrum board serves as a transparent tool that provides a glimpse of what has been completed and what still needs to be done.

Step	Ceremony	Roles	Artefacts	Description
1	Introduction	Product owner		Teachers-as-product-owners face various cultural challenges in Manado. Students answer questions given by the teacher
2	Team forming	Scrum master		Students are divided into 4-5 heterogeneous groups. Each group has its own scrum master, and each member of the scrum team has their own tasks.
			Product backlog	The product owner provides a product backlog and explains the learning objectives/outlines.
3	Sprint planning			Students make plans based on learning objectives and the items loaded.
4			Scrum board	Students use it as a transparent tool to provide a glimpse of what has been completed and what still needs to be done.
5	Sprint			After sprint planning, the scrum team carried out their activities over 4 weeks, with about eight meetings lasting 60-90 minutes each.
6	Stand-up			All team members gather around the Scrum board to discuss several things, namely: (1) what they have worked on in the previous lesson, (2) the contribution they will make in the next lesson, and (3) the problems they face.
7	Daily sprint			Students check progress and adapt backlog sprints as necessary, adjusting upcoming work plans.
8	Sprint visit			Students conduct a comparative study of other Scrum teams to better understand.
9	Sprint review		Formative assessment	Students review based on responses from other scrums. The development of students' creative thinking and entrepreneurial attitudes was reviewed using formative assessments.
10	Sprint retrospective			Students conclude and reflect on what they have done.
11	Final product		Summative assessment	Students give the final product they have created. In addition, summative assessments are carried out.

Table 1: A brief overview of the application of the Scrum method with the ethnochemistry context in learning

The most relevant roles in the Scrum method are the Scrum team, the product owner, and the Scrum master. A scrum team typically consists of 5-9 people and does not include the product owner and the scrum master. Each member of the Scrum team has their own role in producing every product improvement (Rising & Janoff, 2000). Three main principles underlie the Scrum methodology, namely transparency, inspection, and adaptation. Its characteristics are as follows (Schwaber & Sutherland, 2020):

a) Transparency requires active involvement in all phases of the project, ensuring visibility to both the party performing the work and the party receiving it.
b) Inspections, scrum artifacts, and any agreed progress should be checked regularly and diligently to detect any unwanted discrepancies or problems and to provide feedback on the product's quality.
c) Adaptation is carried out if there are aspects of the process that deviate beyond acceptable limits or if the resulting product is unacceptable, the method applied, or the materials produced must be adjusted.

The scrum framework encompasses a range of activities, each of which offers an opportunity to assess and refine scrum artifacts. In Scrum, these activities are used to create regularity and minimize various unspecified findings. Various Scrum activities carried out include sprints, sprint planning, daily scrum, sprint review, and sprint retrospective (Schwaber & Sutherland, 2020). Another scrum activity is sprint visits or sprint events, which are considered the core of the scrum method. The goal is to visualize the progress of each sprint in daily meetings, which significantly affects the quality of communication within the research team and the overall success of the project (Ministr, J., Pitner, T., and Danel, R., 2019).

A typical Scrum project in an educational context begins with the teacher taking on the role of the product owner, conveying complex real-world questions to his students through a clear ceremony. Teachers explain learning objectives, relate real-world questions to students' personal lives, and provide artifacts such as scrum boards and product backlogs that list the exercises and tasks needed to answer those questions (Vogelzang et al., 2020b). Table 1 shows the application of the Scrum method with the ethnochemistry context in the classroom and the learning steps carried out (adapted and synthesized from the research (Vogelzang et al., 2021).

Creative thinking skill

Creative thinking is a cognitive process that each individual uses to analyze, plan, conduct investigations, draw conclusions, and identify assumptions, ultimately leading to the right solution (Ceylan, 2020). Creative thinking skills can be measured through several different indicators, namely the *originality* refers to the extent to which a feature is displayed when a person is given a task to complete; Indicators *flexibility* is an approach seen when a person combines several ideas from different situations to achieve the expected result; Indicators *technique* is a measurement of the quality of the day of the work produced; Indicators *resolution* is an indicator that measures the achievement of the goals of a specific project (Forte-Celaya et al., 2021).

The characteristics of creative thinking skills can be observed from: *fluency* refers to the many ideas generated in responding appropriately related to problem solving; *flexibility* is an approach taken when giving an appropriate response in solving a problem; elaboration is a problem-solving to expand the idea of the stimulus given, detailed steps are taken; originality namely the *originality* of the ideas generated in responding to ideas appropriately and being able to produce new products (Kusumah, 2022). Prahani et al. (2021) explain that creative thinking can be trained through indicators of unusual use, problem discovery, product improvement, scientific imagination, creatively designing experiments, creative problem-solving, and creative product design.

Entrepreneurial attitude

The characteristics of an entrepreneur include self-control, drive to achieve success, strong mental well-being, pragmatism, romantic sentiments, and the spirit to face challenges (Matherne et al., 2020). Characteristics of an entrepreneur (Indarto & Santoso, 2020) that a person must have, namely: (1) creative and innovative; (2) have the ability to analyze the situation**; (3) dare to take risks in taking advantage of opportunities; (4) have good intuition so that they can manage their business more effectively; (5) proactive and daring to compete; (6) have goals and targets to be achieved.**

Other characteristics that entrepreneurs tend to show (Scarborough & Cornwall, 2016) are as follows: (1) a high level of commitment; (2) tolerance for ambiguity; (3) creative; (4) flexible; (5) lots of ideas; (6) willingness to work hard; (7) tenacity. The benefits of business ownership for an entrepreneur include the opportunity to create their own destiny, make a difference, reach their full potential, the opportunity to achieve impressive profits, the opportunity to contribute to society and be recognized for the efforts made, and the opportunity to do what they love and have fun with the results achieved (Scarborough & Cornwall, 2016). The spirit of entrepreneurship is significant because it can enhance the potential of human resources, strengthen students' skills through skill development, and encourage independence and job creation in society (Kamaluddin, 2018).

The main goal of this study was to evaluate whether the Scrum method in ethnochemistry learning leads to greater improvements in creative thinking and entrepreneurial attitude than the scientific approach. A secondary goal was to estimate effect sizes and document implementation challenges, providing evidence for future applications.

This study answers the following research questions:

1. Are there differences in creative thinking skills and entrepreneurial attitudes, respectively, in the application of the Scrum method within the ethnochemistry context, compared to learning with a scientific approach on green chemistry material?
2. Are there significant differences in the conditions before and after the application of the ethnochemistry scrum method to green chemistry in terms of creative thinking skills and entrepreneurial attitudes?
3. What is the effective contribution of the application of the scrum method to the creative thinking skills and entrepreneurial attitudes of students simultaneously and individually?

METHODOLOGY

Research design

This study uses a quasi-experimental design with a pretest-posttest control group to examine improvements in creative thinking skills and entrepreneurial attitudes. The study used two groups: the experimental and the control. The experimental group uses the Scrum method in the ethnochemistry context, while the control group uses a commonly used school-based learning approach, namely, a scientific approach. Scrum was chosen because it provides structured, iterative cycles, visible artifacts (scrum board, product backlog), and role differentiation, which encourage systematic peer feedback and self-regulation. Unlike the conventional scientific approach, which follows linear hypothesis–experiment–report stages, Scrum embeds continuous inspection and adaptation, potentially fostering higher creative ideation and entrepreneurial behaviors (Vogelzang et al., 2021)

Participants

The school sampling technique in this study uses convenience sampling to determine schools. Convenience sampling is a sampling technique based on ease of access and willingness to participate in the study (Creswell, 2014). The sampling process is an essential step in this study to obtain representative data without examining the entire population. Sampling is necessary due to time, manpower, and cost constraints, as well as to ensure the study's results remain valid and generalisable. The research was conducted at a public high school in Manado, involving 110 students from 4 classes. The age range of students in this study was 15-17 years old. Socio-economic background and prior achievement were not controlled. The experimental group (55 students, two classes) comprised 28 females and 27 males. The control group consisted of 55 students from two classes: 31 females and 24 males. The researchers obtained permission from the principal and the school's chemistry teachers.

Research instruments

The Scrum method, with an ethnochemistry context, is applied in a student worksheet that discusses green chemistry in the culture of Manado City. There are three main topics of this learning, namely (1) the importance of green chemistry, the principles of green chemistry, and ethnochemistry processes in daily life; (2) the application of green chemistry principles in the use of alcoholic beverages "saguer" for the manufacture of hand sanitizers; (3) the application of green chemistry principles to the process of making soap from natural ingredients. In this worksheet, the 12 principles of green chemistry are explained, especially in calculating the atomic efficiency of the fermentation reaction of glucose in the beverage "saguer" into ethanol and carbon dioxide, and the atomic efficiency of the reaction of triglycerides with sodium hydroxide to glycerol with soap.

The instrument in this study used an open-ended description test sheet with six questions to measure students' creative thinking skills regarding green chemistry materials, and a questionnaire sheet with 19 items to determine entrepreneurial attitudes. The two instruments were given to students as pre- and post-tests of the learning process using the Scrum method and a scientific approach. Aspects of creative thinking skills and the test instruments used in this study were synthesized from the literature (Ceylan, 2020; Forte-Celaya et al., 2021; Kusumah, 2022; Prahani et al., 2021). Indicators and grids for entrepreneurial attitude instruments were synthesized from the literature (Indarto & Santoso, 2020; Kamaluddin, 2018; Matherne et al., 2020; Scarborough & Cornwall, 2016).

Research procedure

The research was conducted over 6 weeks (the first week for the pre-test and the last for the post-test), and the procedure began with distributing test sheets and questionnaires to students before the lesson. Initially, teachers acting as product owners encountered various cultural challenges in Manado. After that, the teacher explains the various components of the scrum method, and then the students are divided into 4-5 heterogeneous groups. Each group has its own scrum master, and each member of the scrum team has their own tasks.

In the next meeting, the researcher, as a teacher, explained the learning objectives (Figure 2) and the various problems that existed around them. The researcher distributed student worksheets containing multiple products, including problems related to the use of drinking alcohol "captikus", the use of used cooking oil, and waste and product creation. At this stage, students conduct sprint planning based on the loaded learning objectives and items. During sprints, students use the scrum board to indicate what they have done and what to do next. Students conduct daily sprints to check their progress. After discussing in the scrum team, a sprint visit was conducted to gain a deeper understanding of the problems raised. As a result of the sprint visit, the student reviews again. After several scrum series, a sprint retrospective is held to reflect on what has been done. If all these scrum assemblies are considered sufficient, then each scrum team provides the final product in the form of analysis results related to the problems that have been discussed at the meeting.

In the third week, they conducted activities to produce hand sanitizers from alcohol in Manado, applying the principles of green chemistry. Week 4 involved making soap in the city of Manado by combining ingredients, including coconut oil, clove oil, and others, using green chemistry principles throughout the process. In the fifth week, students were given a free practicum to choose between making hand sanitizer or soap. This week, they carried out their own activities without the teacher's guidance. This is done to further develop the various skills they possess. They also conduct a series of sprint activities at each meeting, ensuring learning remains focused.

In the third week, they conducted activities to produce hand sanitizers from alcohol in Manado, applying the principles of green chemistry. Week 4 made soap by applying ingredients in the city of Manado in the form of coconut oil, clove oil, and other ingredients by using green chemistry principles in the process. In the fifth week, students were given a free practicum to choose between making hand sanitizer or soap. This week, they carried out their own activities without the teacher's guidance. This is done to further develop the various skills they possess. They also conduct a series of sprint activities at each meeting to keep learning focused.

Initially, in the control group, teachers also gave worksheets on global problems, but not specific to the culture of the city of Manado. Students form groups, but they are not assigned specific roles. In the core learning activities, students discuss and use the approach that they often use, namely, the scientific approach.

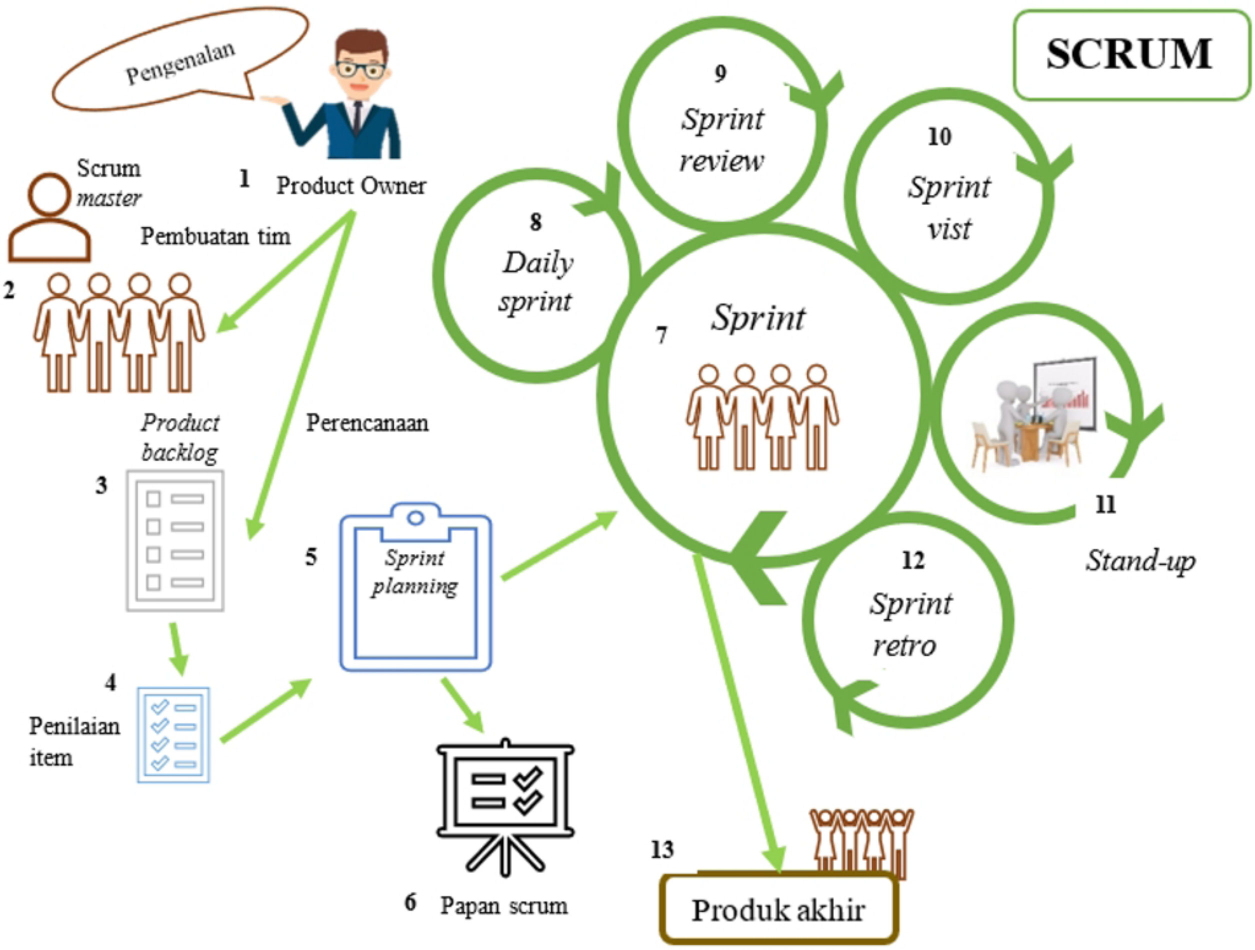

Figure 2: Overview of the Scrum method, taken and synthesized from (Vogelzang et al., 2019)

The control group used the school's standard scientific approach: teacher-led explanation, small group discussion, laboratory tasks, and summative assessments. Unlike Scrum, no role differentiation or systematic formative checks (e.g., stand-ups, backlog reviews) were performed, making this a valid comparator for evaluating Scrum's added value (Vogelzang et al., 2019). Control classes with a scientific approach, without systematic checking, remain valid because they function as a comparison group representing baseline conditions or standard teaching, thereby enabling the attribution of the effects of change to specific elements in the treatment (Scrum with systematic checking). This validity is based on the principle that control classes need not be identical across all aspects of the intervention, as long as they are similar in other characteristics that affect outcomes, such as student demographics or learning context, to isolate the effects of independent variables (Gopalan et al., 2020). This approach is common in educational studies, where control classes often use conventional methods without additional components from the treatment, thereby increasing the internal and external validity of the research. For example, in quasi-experimental designs, control classes help identify causal effects without complete randomization, despite challenges such as selection bias that can be managed through matching or statistical analysis (Brooks et al., 2015; Gopalan et al., 2020).

Reliability and validity of the study

Validity indicates the extent to which an instrument is capable of providing accurate data in accordance with the measurement objectives. Instruments with high validity can accurately measure the desired variables, making validity and reliability tests essential steps in research data collection. In this study, validity tests were conducted theoretically and empirically. Theoretical validity was assessed through expert judgment by three chemistry education professors from Yogyakarta State University for all teaching modules, worksheets, creative thinking skill questions (six essay questions), and questionnaires (20 questions). The results were deemed acceptable after several revisions. Furthermore, the empirical validity of the creative thinking skills questions and the questionnaire was assessed among 243 third-year high school students from three schools in Manado who had studied green chemistry. The empirical validity results show that the six questions are valid, with Pearson correlation coefficients > 0.05 and $p < 0.05$. One item in the questionnaire did not meet the requirements ($p > 0.05$), so 19 items were included. The reliability analysis in this study was conducted by examining Cronbach's alpha coefficients. The reliability of the test instrument was 0.802, which is classified as good reliability, while the reliability of the questionnaire instrument was 0.712, which is classified as moderate reliability.

Data analysis

Data analysis aims to interpret data to inform decision-making or deepen understanding of the observed phenomenon. The data analysis techniques used include inferential statistical methods such as *Normalized-gain* (N-gain), used to determine whether there is an improvement in creative thinking skills and entrepreneurial attitudes. The scores obtained are used to define criteria and establish categories of N-gain effectiveness (Hake, 1998). The N-gain value obtained is then tested using *Multivariate Analysis of Variance* (MANOVA) with prerequisite tests that must be met (Pituch and Stevens, 2016). The results of creative thinking skills and entrepreneurial attitudes showed a significant correlation ($p < 0.05$) with the medium category (Figure 3). All dependent variables showed normal distributions, but the covariance matrix was not homogeneous. After conducting the MANOVA, a paired-samples t-test was used to analyze differences in students' creative thinking skills and entrepreneurial attitudes before and after the implementation of the Scrum method. If there is a significant difference, there is an improvement in their skills and attitudes.

Effect size is used to measure the magnitude of the difference produced by the applied treatment or to assess the extent to which different groups in the population affect dependent variables (Pituch & Stevens, 2016; Stevens, 2009). The multivariate effect size was measured by observing the partial eta square, while the univariate effect size was measured by observing the eta square.

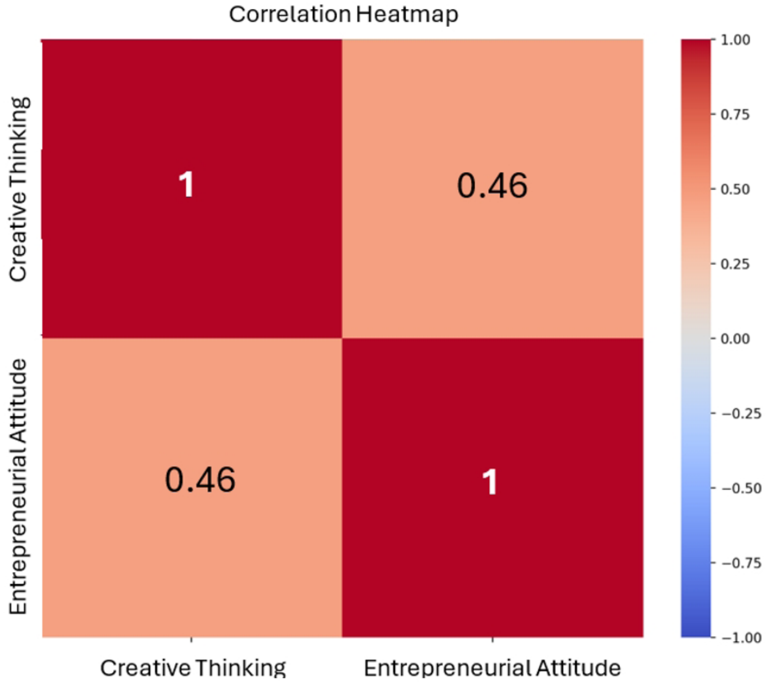

Figure 3: Correlation Between Creative Thinking Skills and Entrepreneurial Attitude

FINDINGS

The results of this study provide an overall overview of the improvement and differences between creative thinking skills and entrepreneurial attitudes of students who use the ethnochemistry context scrum method compared to learning with a scientific approach to green chemistry materials, the results of practical contribution analysis, and differences in creative thinking skills and entrepreneurial attitudes before and after using the ethnochemistry context scrum method.

Students' creative thinking skills and entrepreneurial attitudes

Based on *pre-* and *post-test scores* for six description questions and 19 statement items in the questionnaire, the scores were converted to N-gain values (%) to evaluate the average improvement in students' skills and attitudes. The students' creative thinking skills (Table 2) in the experimental group showed higher post-test scores than in the control group, with an average N-gain of 43.49% and a maximum N-gain of 81.63%. In comparison, the average N-gain in the control group was only 26.34%, and the maximum N-gain was 49.25%. This shows that the creative thinking skills in the experimental group have improved significantly compared to the control class.

The entrepreneurial attitude of students in the experimental group (Table 3) achieved an average N-gain of 26.2% and a maximum of 54.55%. In contrast, students in the control group achieved an average N-gain score of 12.52% and an N-gain value of 27.59. The difference between the two groups was 15.28%, indicating that students in the experimental group had stronger entrepreneurial attitudes than those in the control group.

The results from the experimental group on creative thinking skills and entrepreneurial attitudes suggest that integrating ethnochemistry into the Scrum framework can effectively improve students' abilities. However, the method's complexity may have limited its full potential, suggesting the need for a simpler implementation strategy.

Group	*n*	Average			Value	
		Pre-test	Post-test	N-gain (%)	N-gain min	N-gain maks
Control	55	34.18	5.02	26.24	6.15	49.25
Experiment	55	34.22	63.47	43.49	11.29	81.63

Table 2: Creative Thinking Skills Results

Group	*n*	Average			Value	
		Pre-test	Post-test	N-gain (%)	N-gain min	N-gain maks
Control	55	64.94	69.29	12.52	2.38	27.59
Experiment	55	66	75.36	26.2	4.55	54.55

Table 3: Entrepreneurial Attitudes Results

This is based on the N-gain values for creative thinking skills and entrepreneurial attitudes in the experimental group, which are still classified as less effective and ineffective. However, it shows a significant difference compared to the control group. This is because several psychological factors, such as motivation, independence, and students' emotional state, are closely related to the effectiveness of N-gain in learning (Thomas, Müller, and Bieg, 2018). Motivational factors can significantly affect N-gain. These factors play an important role in shaping learning outcomes and N-gain effectiveness in the learning environment (Putra, and Setiani, 2021). The lower N-gain value is also due to the application of the Scrum method in the ethnochemistry context, which has never been taught in school. This is supported by research (Fernandes et al., 2021), which states that studies on the Scrum method in schools are still exploratory and its application remains very limited.

Differences in students' creative thinking skills and entrepreneurial attitudes

The difference in students' creative thinking skills and entrepreneurial attitudes between the experimental and control groups was evident in the comparison of average pre-test and post-test scores (Tables 4 and 5) and the results of the Pillai's Trace test. The average score on each aspect of creative thinking skills in the experimental group showed a larger difference than in the control group. Each indicator of creative thinking skills in the fluency indicator ($F = 9.532$, $p < 0.05$, $\eta^2 = 0.150$), flexibility ($F = 15.743$, $p < 0.05$, $\eta^2 = 0.226$), elaboration ($F = 5.961$, $p < 0.05$, $\eta^2 = 0.099$) showed that there was a significant difference and had a higher value in the experimental group compared to the control group. Meanwhile, there was no significant difference in the originality indicator ($F = 1{,}711$, $p > 0.05$, $\eta^2 = 0.099$), indicating a small effect. Each aspect of the students › entrepreneurial attitude in the experimental group was optimistic ($F = 15{,}734$, $p < 0.05$, $\eta^2 = 0.226$), making targets ($F = 15{,}042$, $p < 0.05$, $\eta^2 = 0.218$), problem solving ($F = 32{,}080$, $p < 0.05$, $\eta^2 = 0.373$), taking risks ($F = 11{,}986$, $p < 0.05$, $\eta^2 = 0.182$), discovering new things ($F = 22{,}645$, $p < 0.05$, $\eta^2 = 0.295$) showed that there was a significant difference compared to the students in the control group. Meanwhile, in the aspect of self-adjustment ($F = 3.130$, $p > 0.05$, $\eta^2 = 0.055$), there was no significant difference.

The Scrum method's contribution to improving students' creative thinking skills and entrepreneurial attitudes

After applying the scrum method to learning in the context of ethnochemistry, the results showed significant differences in creative thinking skills ($t = -17{,}250$, $p < 0.05$) and entrepreneurial attitudes ($t = -17{,}790$, $p < 0.05$) of students before and after using this method on green chemistry materials. The results showed improvements in their skills and attitudes after implementing the ethnochemistry scrum method. The results of the Pillai's Trace test ($p < 0.05$, partial $\eta^2 = 0.443$) indicated a significant difference in the creative thinking skills and entrepreneurial attitudes of students in the experimental group compared to those in the control group. The application of the Scrum method within the ethnochemistry context in the experimental group yielded highly effective contributions to both variants. Meanwhile, when evaluated separately for each bound variable, the effective contribution to students› creative thinking skills ($F = 35{,}551$, $p < 0.05$, $\eta^2 = 0.248$) and the entrepreneurial attitude of students ($F = 59{,}365$, $p < 0.05$, $\eta^2 = 0.386$).

		Experimental group (*n* = 55)	Control group (*n* = 55)
Fluency	pre-test	5.33	3.38
	post-test	10.69	7.95
Flexibility	pre-test	8.18	7.49
	post-test	12.56	10.11
Elaboration	pre-test	5.98	7.65
	post-test	13.65	11.20
Originality	pre-test	3.27	4.08
	post-test	7.00	6.33

Table 4: Comparison of Average Pre-test and Post-test Scores of Creative Thinking Skills (minimum score = 1; maximum score = 17)

		Experimental group (n=55)	Control group (n=55)
Optimism	pre-test	4.11	3.45
	post-test	3.95	4.35
Creating a Target	pre-test	3.43	3.37
	post-test	4.02	3.65
Troubleshooting	pre-test	3.19	3.45
	post-test	3.97	3.36
Taking Risks	pre-test	3.47	3.29
	post-test	3.99	3.70
Self-Adjustment	pre-test	3.59	3.38
	post-test	3.83	3.62
Discovering New Things	pre-test	3.49	3.61
	post-test	4.04	3.54

Table 5: Comparison of Average Pre-test and Post-test Scores of Entrepreneurial Attitudes (minimum score = 1; maximum score = 5)

DISCUSSION

There were significant differences in creative thinking skills and entrepreneurial attitudes between the experimental and control groups, attributed to the application of the Scrum method within the ethnochemistry context of the experimental class. Based on research data, students showed increased creative thinking skills and entrepreneurial attitudes after applying the Scrum method in the context of ethnochemistry. This is because the Scrum method can provide feedback on the problems and projects being worked on. Research (Jurado-Navas, and Munoz-Luna, 2017) stated that the application of the scrum method can develop the ability to think independently, improve their critical and creative approaches to knowledge, and enhance their ability to collaborate in a team.

In line with research from (Lourakis, and Petridis, 2023) stated that the Scrum framework is not only effective in developing *soft skill* learners, but also showing a much higher success rate for the learners involved in its collaborative approach, the scrum framework encourages the development of communication, cooperation, creativity, and problem-solving skills that are crucial to their employability. In addition, in line with research (Tomás-Miquel, Fotă, Rodríguez-Máñez, P., and Gajownik, 2022), the application of the scrum method in learning can provide stronger motivation and arouse interest in the business aspect, while also helping overcome various challenges.

Learning with the scrum method enables learners to take on a more active role and assume responsibility for their own learning, with teachers shifting the responsibility to them. Teachers play the role of product owners, which requires them to not only monitor the progress of the learning process, but also play a role in interacting with students to provide relevant experiences for students' future careers (Stytsyuk, Lustina, Sekerin, Martynova, Chernavsky, and Terekhova, 2022). The Scrum method encourages learners to be more active in the projects they work on. This scheme starts with the *product backlog*, which provides an overview of what will be done until the final product is produced. Research (Vogelzang et al., 2020b) explained that various events can be related to the basic concepts and principles of green chemistry that can improve their learning, namely; 1) improve conceptual understanding; 2) guide and encourage to reflect on the principles of green chemistry, work on complex real-world problems related to the concept of green chemistry; 3) strengthen their communication, collaboration, and responsibility skills in their socio-cultural environment.

In this study, students were allowed to use their skills to analyze and answer various green chemistry problems related to the culture of Manado. Students in the experimental class use the *product backlog* as their guide in implementing a project. Before addressing the problem, they first use a plan to ensure their project runs smoothly. At the first meeting, which is to answer environmental problems, after doing *sprint planning*, they visit other groups to exchange ideas and provide feedback so that the goals they make can give better results after the visit, the results they get after the visit are written into student worksheets, the results of *sprint planning* and *sprint visit* reviewed by students so that the problems they discuss can provide accurate answers.

The product of this first learning is a solution to environmental problems related to student culture. The solution was then presented in the classroom. The students' presentation results were rewritten in the student worksheet. During the lesson and at the end, students evaluate the findings they obtain. Through a series of scrums, students can become more organized in solving problems, which, in turn, can make them more creative in providing solutions.

Learning activities using the Scrum method in an ethnochemistry context, such as the daily scrum, are important for developing students' creative thinking skills and entrepreneurial attitudes. By participating in these Scrum activities, students will be trained to take responsibility for the project. For example, they utilize natural ingredients from their culture, such as captikus for product manufacturing (Figure 4), as well as hand sanitizers, coconut oil, and clove oil for bath soap production. By applying the principles of green chemistry they have learned, they achieve sustainable practices. When combined with the challenges of social issues, this approach strengthens students' communication and cooperation skills. It helps them take responsibility in their cultural and social contexts (Vogelzang et al., 2020b). The use of the ethnochemistry context scrum method in the classroom is the first step to developing students' skills.

Figure 4: Results of Manufacturing Ethnochemistry Products

Research (Sumarni & Kadarwati, 2020) stated that to strengthen a more meaningful understanding and improve higher-order thinking skills, consistency in applying critical and creative thinking strategies within a culture-based learning approach is essential. (Sudarmin et al., 2023) In his research, he argues that using a local culture-based learning approach can help students strengthen their positive character during the learning process. The use of the ethnochemistry scrum method provides students with a stimulus to apply their creative thinking skills and entrepreneurial attitude when carrying out a project within a team.

The application of the scrum method provides opportunities for skill development and innovation without hindering the learning process, thereby increasing student motivation, as it is based on project management and creativity (Villarrubia et al., 2024). Research (Vogelzang et al., 2020b) suggests that the scrum method in chemistry learning enhances students' understanding of real-life applications and encourages reflection on the principles of green chemistry. (Vogelzang et al., 2021) He also stated that the Scrum method can enhance learning outcomes, stimulate the learning process, reevaluate learning concepts, and increase student involvement in the project. The observed improvements in creative thinking skills and entrepreneurial attitudes in this study, aligns with the constructivist perspective which states that knowledge is formed through an active process of students in constructing meaning based on involvement and learning experiences (Mugambi, 2018), and also aligns with culturally relevant pedagogy which encourages learning by utilising students' cultural background as the core of their learning process (Mathis, and Southerland, 2022). Our results confirm earlier findings that Scrum enhances student engagement in chemistry contexts (Vogelzang et al., 2020b; 2021). However, this study extends prior work by integrating ethnochemistry as a cultural anchor and by examining entrepreneurial attitudes, an outcome not previously assessed in chemistry education Scrum research (Vogelzang et al., 2020a, 2021). The full Scrum cycle may have imposed excessive complexity for novice learners, increasing extraneous cognitive load. This has likely contributed to lower N-gain effectiveness. Future studies should simplify Scrum by phasing in ceremonies, providing teacher training, and systematically monitoring fidelity. Future research could explore the long-term impact of such interventions and their applicability in different cultural contexts. To address the complexity of the Scrum method with ethnochemistry, future research could explore a simplified version or phased implementation to facilitate broader adoption.

CONCLUSION

Based on the results of the research and discussion that have been explained, it can be concluded as follows: (1) there are differences in creative thinking skills and entrepreneurial attitudes simultaneously and each in learning that uses the scrum method in an ethnochemistry context compared to learning with *a scientific* approach on green chemical matter; (2) there were significant differences in creative thinking skills and entrepreneurial attitudes, respectively, before and after using the ethnochemistry scrum method on green chemistry materials; (3) There was an effective contribution of creative thinking skills of 24.8% and entrepreneurial attitude of 38.6% of students who used the scrum method in the context of ethnochemistry on green chemistry materials and simultaneously by 44.3%. The findings show that applying the scrum method in the context of ethnochemistry increases creative thinking skills and entrepreneurial attitudes. Based on the findings and analysis that have been described, several suggestions can be considered for future research, namely the application of scrum method with ethnochemistry context can be added several chemical projects to improve students' creative thinking and entrepreneurial attitudes, the application of scrum method with ethnochemistry context can be done by adding other variables, further research can be carried out according to the cultural background of other regions.

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Full research paper

EXPLORING THE EFFECTS OF EXPLICIT SCIENCE PROCESS SKILL INSTRUCTIONS ON PRIMARY SCHOOL PRE-SERVICE SCIENCE TEACHERS NATURE OF SCIENCE CONCEPTION

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ABSTRACT

Informed Nature of Science (NOS) conception is among the professional competencies of science teachers. As a result, extensive research is being conducted on the development of NOS conceptions among pre-service science teachers (PSSTs). However, it remains a significant challenge, particularly because NOS is a meta-concept that necessitates higher-order cognitive skills. In this study, we explored the influence of explicit Science Process Skill (SPS) instruction on the PSST's NOS conception using a quasi-experimental pretest-posttest design with experimental and control groups. SPS is instructed using the four-component instructional design (4C/ID) model. Findings indicated that PSSTs had a less informed conception of NOS, its various themes, and laws vs. theories and methodologies in scientific investigation. Observation and inference, the tentativeness of scientific theories/knowledge, the existence of creativity and imagination in science, and scientific methodology were significant themes of NOS.

On the other hand, laws vs. theories and society and cultural influence on science themes do not show significant improvements. This study demonstrated that explicit SPS instruction is a better framework for developing specific themes of NOS conception. However, it also highlighted the limitations of a single method in altering entire themes, emphasizing the need for an appropriate method for each theme.

KEYWORDS

Explicit skill instruction, four-component instructional design, nature of science, science process skill

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Highlights

- *PSSTs had a less informed conception of NOS as a whole and its various themes.*
- *Explicit SPS instruction significantly improved observation and inference, the tentativeness of scientific theories/ knowledge, the presence of creativity and imagination in science, and the NOS themes of scientific methodology.*
- *A single method has limitations for developing all NOS themes; thus, it needs to adopt an appropriate strategy for each theme.*

INTRODUCTION

Improving students' scientific literacy is a pivotal objective in primary school science education and is advocated by various national educational standards (Neumann et al., 2017). A comprehensive grasp of the Nature of Science (NOS) constitutes a fundamental aspect of scientific literacy. Furthermore, it is recognized as a crucial professional competency of science teachers. Research shows that science teachers with an informed understanding of NOS effectively integrate NOS teaching methodologies into their classrooms (Capps & Crawford, 2013) and are more adept at cultivating dynamic inquiry-based learning settings (Abd-El-Khalick, 2013). Driver et al. (1996) highlighted five benefits of students learning about the NOS, namely: understanding the science process, making informed decisions on socio-scientific issues, appreciating science, being aware of scientific community

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norms, and learning deeper science content. Nevertheless, prior studies have revealed that the majority of both in-service and pre-service science teachers (PSSTs) harbor misconceptions about NOS (Abd-El-Khalick and Akerson, 2004; Liang et al., 2009; Cofre et al., 2019).

Teachers' preparation at the higher education level is a crucial stage for professionalization and competence enhancement, making it an essential initial step in fostering an informed understanding of the NOS. Various research studies have previously been conducted to identify effective strategies for improving PSSTs' understanding of NOS in their preparation programs. The widely used strategies are implicit and explicit instructions. Implicit instruction strategies involve using the history of science and hands-on inquiry-based scientific activities (Khishfe & Abd-El-Khalick, 2002; Allchin et al., 2014). On the other hand, explicit instructions are provided through NOS themes in explicit-reflective (stand-alone topic) form or integrated into a scientific context (Bell et al., 2011). Mesci and Schwartz (2017) highlight that efforts to enhance PSSTs' NOS have been limited successes, since it is more difficult to understand certain aspects of NOS than others. According to Erduran and Kaya (2018), one critical reason is that the NOS is a metacognitive concept that demands higher-order cognitive skills.

Science process skills (SPS) are cognitive and psychomotor skills used by scientists to investigate and acquire scientific knowledge (Ozgelen, 2012). They encompass scientific practices such as observation, experimentation, prediction, data analysis and interpretation, inference, and hypothesis formulation. Several studies (Dirks & Cunningham, 2006; Coil et al., 2010; Shah & Hoeffner, 2002; DebBurman, 2002; Kruit et al., 2018; Aktamis & Ergin, 2008; Aslan & Kilic, 2022) indicated explicit instruction of SPS was effectively used for the development of SPS among students and teachers. For instance, Kruit et al. (2018) argued that explicit instruction of inquiry skills by using a four-component instructional design model (4C/ID) (Van Merrienboer et al., 2002) effectively aids in the acquisition and transfer of students' science inquiry skills across various content areas. Moreover, studies indicate SPS developments are helpful for mastery of contents in constructivist, discovery, problem-based, experiential, and inquiry-based teaching approaches (Kirschner et al., 2006; Lazonder & Harmsen, 2016), improve students' control of variables when combined with practice (Dean & Kuhn, 2007), aid in metacognitive skill development (Tanner, 2012), and play a crucial role in facilitating the transfer of skills beyond the initial learning environment (Klahr & Li, 2005).

Studies that focus on the contribution of SPS development through explicit instruction on NOS conception are limited in the literature. Researchers argue that NOS conceptions are connected to understanding how knowledge is built (Abd-El-Khalick & Akerson, 2004) and involve metacognitive concepts that demand higher-order cognitive skills (Erduran & Kaya, 2018). SPS are among the ways of doing science and metacognitive skills. This study explores PSSTs' understanding of NOS and the effect of 4C/ID-based explicit SPS instruction on their NOS conceptions in science. The study hypothesizes that enhancing PSSTS's SPS practices will positively impact their NOS conceptions, considering the overlap and mutuality between these themes. We included the following section: literature reviews on SPS and NOS conception; the study's methodology, including the basic concepts of the four-component instructional design; results on NOS conceptions and their change due to the intervention; discussions; and, finally, conclusions.

REVIEW OF LITERATURE

Science Process Skills (SPS)

SPSs are the foundational abilities that develop and are utilized in the process of scientific inquiry and investigations. They are typically categorized into basic and integrated skills (AAAS, 1967). Basic skills encompass: observation, measurement, classification, inference, prediction, communication, and questioning. Conversely, integrated skills include: defining operations, identifying and controlling variables, formulating hypotheses, conducting experiments, analyzing and interpreting data, graphing, and modeling processes. These skills are universally transferable; therefore, they are not only essential in science classrooms but also in various aspects of everyday life and in other academic disciplines.

The development of SPS among teachers is crucial for enhancing the quality of science education. Evidence from research indicates teachers with strong SPS have the capability to design and facilitate engaging, inquiry-based lessons that promote active learning (Anderson, 2002), promote student academic achievement, critical thinking, and problem-solving skills, and mastery of subject matter (Susantia et al., 2018), and introduce effective learning and development of SPS among students (Mutisya et al., 2013). Teachers with a deep understanding of SPS can contribute to the development of curriculum materials that align with best practices in science education (Bybee, 2013) and to more effective and accurate assessment of students' understanding of SPS (National Research Council, 2014). Moreover, Bybee (2013) suggests that teachers cultivating their own SPSs foster a similar learning mindset, incorporate new technologies, and promote a culture of scientific discovery and innovation in their classrooms.

Gizaw and Sota (2023) provided a detailed review of the literature on possible strategies for developing science process skills across studies. The findings revealed that integrating SPS into curricular materials, classroom lesson presentations, and assessments, using multiple-representation teaching approaches, and explicitly instructing students in science process skills help develop students' science process skills. Multiple representation teaching approaches involve employing various teaching methods, such as descriptive, mathematical, analogical, and kinesthetic, in combination in the same lesson or using multiple media like models, flowcharts, real specimens, and video within the same lesson. Explicit instruction or training of SPS entails utilizing programmed instruction methods by developing teaching or training materials similar to those used for content delivery.

Many studies (Kirschner et al., 2006; Lazonder & Harmsen, 2016) underscore the importance of explicitly teaching skills in constructivist, discovery, problem-based, experiential, and inquiry-based teaching. These studies indicate that more effective learning occurs when the aforementioned teaching methods are accompanied by explicit skill instruction. Research also underlines that explicit skill instruction is more effective when combined with practice. For instance, Dean and Kuhn (2007) showed that explicit instruction, particularly when students were prompted to compare and identify various features of catalogs, improved students' control of variables more when combined with practice. Moreover, explicit skill instruction with a direct focus on task awareness and the utilization of metacognitive strategies could aid in metacognitive skill development (Tanner, 2012). According to Klahr and Li (2005), explicit instruction in skills appears to play a crucial role in facilitating transfer beyond the initial learning environment.

SPSs are rarely explicitly taught to students and scaffolded, as it is believed they are acquired through learning by doing (Dean & Kuhn, 2007). However, researchers argue that SPS needs to be taught with intentionality because it does not develop spontaneously (Zimmerman, 2000). There is ample evidence that explicit instructions foster SPS and related variables. For instance, Dirks and Cunningham (2006) reported that providing explicit instructions on SPS helps undergraduate students enhance SPS, content acquisition, and interdisciplinary thinking. Coil et al. (2010) noted earlier that explicit teaching of SPS is essential to improving student success and retention in the sciences and to enhancing general science literacy among undergraduate students. Shah and Hoeffner (2002) found that students who received explicit instruction in generating and interpreting scientific graphs benefited from improved learning and reinforcement of course content. Likewise, DebBurman (2002) reported that explicitly teaching SPS integrated with content helped students acquire the content more readily and prompted them to recognize the need to improve their proficiency in these areas. Moreover, Kruit et al. (2018) argued that explicitly teaching SPS effectively improves students' SPS at primary education levels. Aktamis and Ergin (2008) argued that SPS education led to meaningful changes in middle school students' scientific creativity and academic achievement. The literature reviewed confirms that explicit instruction in SPS, implemented systematically and structured for pre-service teachers and other students, significantly contributes to the development of their SPS. In this study, SPSs were instructed in PSSTs using the 4C/ID framework, and their influence on NOS conception was investigated.

Nature of science

According to Lederman (2019), in science education, NOS refers to the values and beliefs of science, the characteristics of scientific knowledge and its production, how science impacts and is impacted by society, and what scientists look like in their professional and personal lives. Science educators view NOS from various perspectives, including the consensus view and the Family Resemblance Approach (FRA). The consensus view conceptualizes NOS as a set of statements, called aspects or themes. As specified by Kampourakis (2016) and Fraser et al. (2012), the most common NOS themes are: observation and inference are different; the tentativeness of scientific theories and knowledge; scientific laws and theories are distinct forms of knowledge; scientific knowledge is influenced by the cultural contexts in which it is developed; scientific knowledge involves human imagination and creativity; and various methodologies are used in scientific investigations. The conceptualization of NOS as tenets is a practical and effective method for teaching and learning NOS in K-12, pre-service, and in-service teacher education (Fraser et al., 2012). Moreover, it enables us to easily address misconceptions about how science works and what scientific knowledge is among teachers and students.

FRA conceptualizes the branches of science as a family, where each member is unique yet shares common features. In each science domain, features such as aims and values, methodologies and methodological rules, scientific activities, and the products of science (knowledge) are applied to describe and explain science and to conduct analysis (Matthews, 2014). This makes FRA widely applicable to various branches of science. FRA is further refined into the Reconceptualized Family Resemblance Approach to Nature of Science (RFN) by including social-institutional aspects of science, such as political and financial dynamics, social hierarchies, and organizational factors, as these factors significantly influence science operations (Erduran & Dagher, 2014). Although we acknowledge the multiple competing ways to conceptualize NOS for K–12 students and teachers, we adopt a consensus conceptualization of NOS in this study. This method is practical and effective in teaching and learning, addressing misconceptions about science and its workings (Kampourakis, 2016).

Effective teachers who are well-equipped with professional competencies are critical factors for student learning. Informed conceptions of NOS are among the professional competences of science teachers. For instance, science teachers with adequate NOS conceptions integrate NOS teaching practices in their classrooms (Capps & Crawford, 2013). They are more adept at cultivating dynamic inquiry-based learning settings (Abd-El-Khalick, 2013). Several studies have shown that pre-service teachers' NOS conceptions are naïve, uninformed, and mixed (Abd-El-Khalick & Akerson, 2004; Liang et al., 2009; Cofre et al., 2019; Mesci, 2020; Zion et al., 2020; Wang et al., 2023).

More frequently, science education researchers apply implicit and explicit NOS instruction approaches to their development. According to Khishfe and Abd-El-Khalick (2002), the implicit approach uses hands-on inquiry-based activities and the historical context of science to teach certain aspects of the NOS, viewing NOS conceptions as a hidden outcome. The explicit approach focuses on the deliberate and systematic teaching of the NOS, presenting philosophical concepts and exercises directly to foster a comprehensive understanding of the NOS as a stand-alone topic or integrated into a scientific context (Khishfe & Abd-El-Khalick, 2002; Allchin et al., 2014). Studies show that explicit instruction is more effective than implicit instruction in promoting NOS understanding, regardless of whether it's explicit-reflective (standalone topic) or embedded in a specific context, such as specific science content, the history of science, socio-scientific issues, or science inquiry (Bell et al., 2011; Fraser et al., 2012).

Mesci and Schwartz (2017) argued that efforts to enhance PSSTs' NOS have been limited successes, even when explicit-reflective instruction is provided. Some aspects of NOS are more difficult to understand than others. This highlights the difficulty in producing comprehensive NOS understanding through specific strategies and encourages the exploration of suitable strategies for specific NOS themes. Regarding several alternative strategies for either approach, different researchers have tested them. For instance, Bell et al. (2016) used a context continuum approach, combining highly science-content-contextualized and non-contextualized approaches. The results indicated that teaching and scaffolding NOS lessons along a science content context continuum can be effective in eliciting desired changes in preservice teachers' NOS conceptions.

On the other hand, Abd-El-Khalick and Akerson (2009) explored the influence of metacognitive training on preservice elementary teachers' conceptions of NOS. The results point to a relationship between improved metacognitive awareness and the development of informed understandings of NOS. More recently, Erduran and Kaya (2018) used visual representations of scientific knowledge and practice aspects as tools for developing and monitoring understanding of NOS conception among PSSTs. Their findings indicated improvements in pre-service teachers' perceptions of the NOS.

SPS focuses on practical methods and techniques used in scientific investigation, while NOS delves into the underlying beliefs about knowledge and its acquisition process. SPS and NOS are not mutually exclusive; rather, they interact (Abd-El-Khalick & Akerson, 2004). For instance, observation and inference are found in both SPS and NOS. Moreover, SPS skills such as observation, experimentation, classification, and prediction serve as methodologies for producing scientific knowledge, which is among the themes of NOS (Erduran & Kaya, 2018). Thus, issues related to NOS can be addressed within the framework of explicit SPS instructions. For instance, Bell et al. (2011) assessed the effect of a process skills-based instruction approach on the NOS views of 17 pre-service teachers. The study found that the process skills-based approach effectively develops informed NOS conceptions among pre-service teachers. Research exploring the relationship between SPS and NOS development is sparse. Specifically, there is a lack of studies investigating how explicit instruction in SPS influences NOS understanding of PSSTs.

Research questions

NOS conception plays a crucial role in enhancing a deeper understanding of science content knowledge, how science works, and how scientific knowledge is generated (Driver et al., 1996). The study aims to investigate the impact of explicit SPS instruction on PSSTs' conception. Therefore, our study addresses the following research questions:

RQ 1. What are the NOS conceptions of PSSTs?

RQ 2. How and in what ways do NOS conceptions of PSSTs affect by explicit SPS instructions?

MATERIAL AND METHODS

Participants

This research enlisted 69 PSSTs undergoing training to teach science subjects in primary schools at Arba Minch Education College. All participants had a science background from their high school education and were in their second year of pre-service teacher training, taking their initial science courses at the college level, including General Biology, General Physics, and General Chemistry. Of the 69 students, 36 were male, and 33 were female, with ages ranging from 18 to 24 years.

Research design

The study used a quasi-experimental pretest-posttest controlled-group design, with participants randomly assigned to either the experimental or control condition. The experimental group received the recruitment: pre- and post-test, pre- and post-interview, and intervention through explicit SPS instruction. In contrast, the control group received only pre- and post-test and pre- and post-interview. The interview comprised 12 participants, including six from the control group and six from the experimental group, selected based on their pre-test scores. In each group, three PSSTs had the lowest pre-test scores, while the remaining three had the highest. The pre-interview took place during the second week of the semester, and the post-interview occurred one week before the semester's conclusion. The aim of the interview was to understand participants' NOS conceptions before and after the intervention.

Intervention strategy

The intervention was undertaken using the four-component instructional design model (4C/ID) developed by Van Merriënboer et al. (2002). According to the designers, it is a new approach to training programs for complex skills where transfer is the primary learning outcome rather than content knowledge. In the past, the common practice was to teach individuals by starting with smaller components or tasks and gradually building up to the complete task. However, the new whole-task approach, known as the 4C/ID model, reverses this process. Instead of starting with parts and moving towards the whole task, individuals are first exposed to simplified versions of the entire task, with complexity gradually increased until the complete task is mastered. The 4C/ID model comprises four components: two task components (learning tasks and part-task practice) and two information components (supportive information and just-in-time information). It was used by Krui et al. (2018) and found to be effective for developing students' science inquiry skills and for their transfer across different contexts.

Learning or whole tasks are concrete and authentic experiences that provide meaningful scientific inquiries for learners, integrating skills, knowledge, and attitudes. They include case studies, projects, and problems organized in easy-to-difficult task classes. Part-task practice is a method of strengthening skills through repeated exposure and practice. It involves refining specific aspects of a skill, allowing learners to perform routine tasks automatically without conscious thought. This process is crucial for achieving proficiency and mastery of the overall task.

Supportive information is crucial for students to undertake tasks or engage in scientific inquiry, yet they often lack it. It is provided early and during task engagement through lectures, data organization exercises, and systematic problem-solving approaches. Supportive information can explain problem approaches, suggest domain organization, or offer foundational knowledge. It bridges learners' existing knowledge with what they need to work on in learning tasks. The process of learning from supportive information is elaboration, connecting new information to existing knowledge. Just-in-time or procedural information refers to the necessary information needed during tasks, such as essential clues, knowledge, feedback, and prompts, to help students gain proficiency in skills. It outlines how to perform routine tasks until students gain proficiency in the skills, and then withdraw gradually. Knowledge compilation is the fundamental mechanism for learning from just-in-time information. It involves assimilating new information into cognitive rules.

For SPS instruction, an explicit instruction manual was prepared based on a 4C/ID model developed by researchers. The manual contains 12 SPS for instruction: basic SPS (observation, classifying, measuring, and using numbers, making inferences, predicting, and communication) and integrated SPS (defining operationally, identifying and controlling variables, interpreting data, making hypotheses, experimenting, graphing, and modeling). The selected tasks offered practice variability and opportunities, appropriate difficulty levels, and optimal support and guidance. Task classes were sequenced from easy to difficult, with performance objectives set for each task to assess student performance and provide feedback. Supportive and procedural information was designed for each task based on cognitive rules, mental models, and prior knowledge. Finally, part-task practice was used sparingly in learning tasks to enhance performance on routine aspects of the task when a high level of automaticity was desired. The prepared material underwent validation by two science education experts to determine its suitability for training SPS skills. The SPS instruction was provided to pre-service teachers for approximately 12 weeks. One science teacher educator, assigned from Arba Minch Education College, conducted the instruction under the researcher's supervision.

Data collection tool

The students' understanding of science and scientific inquiry scale (SUSSI) questionnaire is used to collect data. SUSSI is an instrument designed with both Likert-scale and open-ended components to provide opportunities for in-depth study of NOS views among pre-service teachers (Liang et al., 2008). The questionnaire considers only six themes or aspects of NOS: observations and inferences; the tentative nature of scientific theories/knowledge; scientific laws and theories; social and cultural influences on science; imagination and creativity in scientific investigations; and methodology in scientific investigations. Each theme consists of four Likert items (covering both the most common naive and informed views, as well as positive and negative items) and one open-ended question. Therefore, the scale comprises 24 items and six open-ended questions. An analysis was made after negative items were scored reversely. The Cronbach's alphas of the subscales are: observations and inferences (0.61); tentative nature of scientific theories (0.56); scientific laws vs. theories (0.48); social and cultural influence on science (0.64); imagination and creativity in scientific investigations (0.89); and methodology in scientific investigations (0.44). The overall Cronbach's alpha for the entire instrument is 0.69. The SUSSI open-ended questions were used for a semi-structured interview.

Data analysis

Quantitative data were analyzed using descriptive and inferential statistics (paired-samples t-test, independent-samples *t*-test, and repeated-measures MANOVA) in the Statistical Package for the Social Sciences (SPSS). Normality assumptions were assessed using skewness and kurtosis, and Levene's test was used to assess homogeneity of variances. The sex comparability of groups was assessed using a chi-square test, while the academic and pre-test comparability was checked using an independent t-test. The effect size indicates the relative magnitude of differences or relationships between groups. Qualitative data from interviews were analyzed using the SUSSI rubrics for open-ended questions (Liang et al., 2009), which classify responses for each NOS theme into: not classifiable, naïve, transitional, and informed. Views reported is not classifiable if: there is no response; they state that they do not know; the response does not address the prompt, naïve if the participant's views did not agree with currently accepted consensus view of that particular aspect of NOS (example: Scientists' observations AND/OR interpretations are the same because scientists are objective), transitional if the participant's views agree with currently accepted consensus view of that particular aspect of NOS, but lacks appropriate explanations, justifications or examples (example: the observations AND/OR inferences may be different) and informed if the participant's views agree with currently accepted consensus view of that particular aspect of NOS and contain appropriate explanations, justifications and examples (example: Scientists' observations and inferences may be different because of their prior knowledge, personal perspective, or beliefs).

RESULTS

Prior intervention NOS conceptions

Initial data checks revealed that the distributions of NOS scores for each NOS theme met the assumptions necessary for the analysis of variance. The data for each NOS theme and the overall NOS were found to be normally distributed based on kurtosis and skewness tests. Additionally, Levene's test indicated that the data were homoscedastic. The experimental and control groups were comparable in terms of sex, academic grade point average (GPA), and pre-test scores on four NOS themes (observation and inferences, social and cultural influence on science, imagination and creativity in scientific investigations, and methodology of scientific investigation). For our study sample, the Cronbach's alphas of the pre-test and post-test subscales are as follows: 0.56 and 0.59 for observation and inferences, 0.54 and 0.53 for the tentative nature of scientific theories, 0.47 and 0.61 for scientific laws vs. theories, 0.65 and 0.62 for social and cultural influence on science, 0.73 and 0.66 for imagination and creativity in scientific investigations, and 0.43 and 0.61 for methodology in scientific investigations, respectively. The pre-test and post-test overall Cronbach's alphas for the entire instrument are 0.70 and 0.84, respectively. The low Cronbach's alpha could be attributed to the small sample size and the presence of negative items in each subscale.

The descriptive statistics from the pre-test (Table 1) indicate that the PSSTs exhibited less informed conceptions regarding observation and inferences, the tentativeness of scientific theories, social and cultural influences on science, and imagination and creativity in scientific investigations. Conversely, they held uninformed views regarding laws vs. theories and the methodology of scientific investigation. Generally, the pre-test data indicate that the PSSTs' NOS conception is not at an adequate level across the overall and specific NOS themes.

NOS themes	Pre-tests		Post-test	
	M	*SD*	*M*	*SD*
Observation and inferences	3.27	.86	3.78	0.87
Tentativeness of scientific theories	3.45	.89	4.06	0.72
Scientific Laws Vs. theories	2.91	.67	3.07	0.87
Social and cultural influence on science	3.23	.96	3.62	0.9
Imagination and creativity in scientific investigations	3.43	.98	3.71	0.9
Methodology of scientific investigation	3.04	.75	3.49	0.97
Overall NOS conception	3.22	.47	3.62	0.6

Table 1: Pre-and post-test of all participants (*N* = 69) (Source: own calculation)

Changes in NOS conception

Table 2 displays the descriptive statistics for the pre- and post-tests of the experimental and control groups, along with the interactions between the groups (experimental and control) and the pre- and post-tests. On each NOS theme and overall NOS conception, examined through repeated measures MANOVA. The descriptive statistics reveal a general increase in scores from pre- to post-test for NOS themes in both groups, except for the social and cultural influence on science theme within the control group. Analysis using Wilks's statistic for within-subjects effects indicated significant time and group interactions in the NOS themes: observation and inference ($\Lambda = .89$, F(1,67) = 8.5, $p = 0.005$, $\eta^2 = 0.113$), tentativeness of scientific theories ($\Lambda = .81$, $F(1,67) = 8.84$, $p = 0.00$, $\eta^2 = 0.19$), imagination and creativity in scientific investigations ($\Lambda = .91$, $F(1,67) = 6.93$, $p = 0.01$, $\eta^2 = 0.094$), methodology of scientific investigation ($\Lambda = .89$, $F(1,67) = 8.148$, $p = 0.006$, $\eta^2 = 0.108$), and overall NOS conception ($\Lambda = .83$, $F(6,67) = 13.7$, $p = .00$, $\eta^2 = .17$). This was further supported by paired *t*-tests, indicating a significant increase in observation and inferences ($t(67) = 2.96$, $p = .004$), tentativeness of scientific theories ($t(67) = 3.4$, $p = 0.001$), imagination and creativity in scientific investigations ($t(67) = 2.15$, $p = 0.035$), methodology of scientific investigation ($t(67) = 3.091$, $p = 0.003$), and overall NOS conception ($\Lambda = .83$, $F(1,67) = 13.7$, $p = .00$, $\eta^2 = .17$) within the experimental group (Table 3). However, the effect sizes for the time-by-group interaction were small for each NOS theme and for the overall NOS conception.

NOS themes	Experimental group (*n* = 36)				Controlled group (*n* = 33)						
	Pre-test		PostPre-test		retest		Post-test		Time *group interaction		
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*P*	Partial η^2
Observation and inferences	3.22	0.93	4.06	0.75	3.32	0.97	3.47	0.89	8.51	0.005	0.11
Tentativeness of scientific theories	3.22	0.87	4.32	0.55	3.69	0.85	3.77	0.77	8.84	0.00	0.19
Scientific Laws Vs. theories	2.78	0.62	2.94	0.98	3.05	0.7	3.2	0.73	0.003	0.95	0.00
Social and cultural influence on science	3.06	0.95	3.64	0.82	3.42	0.95	3.59	0.99	1.81	0.183	0.03
Imagination and creativity in scientific investigations	3.32	0.94	3.93	0.79	3.55	1.03	3.48	0.79	6.93	0.01	0.09
Methodology of scientific investigation	3.01	0.78	3.8	0.81	3.08	0.78	3.13	1.02	8.148	0.006	0.11
Overall NOS conception	3.10	0.44	3.78	0.42	3.35	0.47	3.44	0.71	13.7	0.00	0.17

Table 2: Mean scores and the interaction effects (time of measurement * group) for each NOS theme (Source: own calculation)

Paired-samples *T*-tests were employed to assess the mean differences between pre- and post-scores for each of the six NOS themes and the overall NOS conception in both experimental and control groups. The results indicate significant differences (increases) between pre- and post-scores for all five NOS themes except for Scientific Laws vs. Theories ($p = 0.36$) in the experimental group (Table 3). Similarly, paired-samples *t*-tests on pre- and post-scores for each of the six NOS themes in the control group reveal no significant differences. Following Cohen et al.'s (2018) classification of effect sizes, observation and inferences, the tentativeness of scientific theories, the methodology of scientific investigation, and the overall NOS conception exhibited strong effect sizes, while social and cultural influence on science, and imagination and creativity in scientific investigation, demonstrated moderate effect sizes. Conversely, scientific laws vs. theories displayed a poor effect size in the experimental group (Table 3). All six NOS themes and the overall NOS conception exhibited poor effect sizes in the control group.

NOS themes	Experimental group (*N* = 36)				Controlled group (*N* = 33)			
	t	*df*	*Sig.*	Effect size (Cohen's *d*)	*t*	*df*	*Sig.*	Effect size (Cohen's *d*)
Observation and inferences	-5.628	35	.000	1	-.828	32	0.414	0.18
Tentativeness of scientific theories	-6.342	35	.000	1.55	-.432	32	0.669	0.1
Scientific Laws Vs. theories	-.927	35	.360	0.2	-.803	32	0.428	0.21
Social and cultural influence on science	-2.586	35	.014	0.67	-.870	32	0.391	0.17
Imagination and creativity in scientific investigations	-3.401	35	.002	0.7	.400	32	0.692	0.07
Methodology of scientific investigation	-4.337	35	.000	1	-.287	32	0.776	0.08
Overall NOS conception	-6.380	35	.000	1.58	-.749	32	0.459	0.15

Table 3: Paired t-test comparison for Experimental and Controlled groups pre- to post-test means (source: own calculation)

Comparisons of experimental and control group post-tests using independent *t*-tests revealed statistically significant differences between the groups in NOS themes: observation and inferences, tentativeness of scientific theories, imagination and creativity in scientific investigations, methodologies in science, and overall NOS conception (Table 4). For these NOS themes, as per Cohen et al. (2018), the effect sizes were moderate.

NOS themes	*t*	*df*	*Sig.*	Effect size (Cohen's *d*)
Observation and inferences	2.963	67	0.004	0.71
Tentativeness of scientific theories	3.405	67	0.001	0.82
Scientific Laws Vs. theories	-1.239	67	0.220	0.3
Social and cultural influence on science	.220	67	0.827	0.05
Imagination and creativity in scientific investigations	2.148	67	0.035	0.52
Methodology of scientific investigation	3.091	67	0.003	0.75
Overall NOS conception	2.465	67	0.016	0.6

Table 4: Independent *t*-tests for post-test mean comparison of each theme and overall NOS conception (Source: own calculation)

The interview responses corroborated the quantitative findings, demonstrating significant improvements in various aspects of NOS within the experimental group. The existing literature on PSSTs' NOS conception suggests that informed conceptions are characterized by a viewpoint on which scientific agreements are reached and by providing appropriate explanations, justifications, and examples. The following sections delve into the development of participants' specific NOS conceptions, supported by interview data. Sample responses from participants (three from each group) and their corresponding levels of NOS conception are presented in Tables 5 and 6. The interview responses are detailed, including the individual's identifier, their group (experimental or control), the interview phase (pre- or post-interview), and their specific level of NOS conception. For instance, 1E-2: *naïve* refers to the first participant in the experimental group exhibiting a naïve conception during the second interview.

Prior to intervention, the observation and inference NOS theme appeared to be more transitional among participants in both groups. However, post-interview findings revealed that the experimental group (1E-2: *Informed*; 2E-2: *Informed*; 3E-2: *Informed*) showed greater improvements in their conception levels for the NOS theme of inference and observation than the control group (1C-2: *Transitional*; 2C-2: *Naïve*; 3C-2: *Informed*). Regarding the tentative nature of NOS scientific theories, participants in both the experimental and control groups held similar conceptions in pre-test interviews. Most of them indicated that scientific theories do not change (1E-1: *Naïve*, 3E-1: *Naïve*, and 2C-1: *Naïve*). However, participants in both groups had informed conceptions of this theme before the interventions (2E-1: *Informed* and 1C-1: *Informed*). Following the intervention, the NOS conceptions of the tentativeness of scientific theories/knowledge among most participants in the experimental group shifted more positively than those in the control group (1E-2: *informed*; 2E-2: *informed*; 3E-2: *informed*).

In both groups, the PSSTs' conception of the scientific theory vs. law NOS theme was predominantly naïve and difficult to classify. Following the intervention, the pre-interview conceptions were largely retained in both groups. Conversely, regarding social and cultural influence, the controlled group exhibited a more positive pre-interview stance (1C-1: *informed*; 3C-1: *informed*) compared to the experimental group (1E-1: *Naive*; 3E-1: *Naive*). While participants in the experimental group (1E-2: *transitional*; 3E-2: *transitional*) showed improvements in conception, most participants in the control group maintained their pre-interview conceptions.

In the pre-interviews of both experimental and control groups, the presence of imagination and creativity was perceived as naïve and transitional. However, qualitative data suggested that positive

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progress was more evident in the experimental group (1E-2: *informed*; 2E-2: *informed*; 3E-2: *informed*) compared to the control group (1C-2: *transitional*; 2C-2: *transitional*; 3C-2: *transitional*) in the post-interview. Most participants in both groups held a naïve conception of the methodology of scientific investigation prior to the interview. Following the intervention, the experimental groups significantly shifted their conception to an informed level, whereas no progress was observed in the control group.

NOS theme	Pre-interview	Post-interview
Observation and inferences	I think it is the same, because all scientists are critical workers. (1E-1: *Naive*)	It is different. Some scientists may make critical observations while others make shallow ones. This makes them have different information from their observation. Since what they observed differs, their inferences may differ as well. (1E-2: *Informed*)
	It is different. One thing cannot be observed in the same way by different scientists. (2E-1: *Tranistional*)	Not the same. It is different. Individuals' prior knowledge and experience affect their observations. For example, in our laboratory classes, we do not always observe the same thing in the same way. Also, students sometimes make different inferences from the same observation. (2E-2: *Informed*)
	I feel it would be different. I think it may depend on the human. (3E-1: *Transitional*)	They do not make the same observations and inferences. It can be the same for certain events, yet different as well. Observation may depend on the sense organs and instruments used. (3E-2: *Informed*)
Tentativeness of scientific theories/ Knowledge)	Scientific theories do not change. Theories are established after several critical experiments. (1E-1: *Naive*)	Theories change. Theories are formulated based on experimental data. Data from observation and experiments may change when methods change. If the data change, the theory formulated may change. (1E-2: *Informed*)
	Theories change. Example: the theory of spontaneous generation changed in biology. (2E-1: *Informed*)	Scientific theories are exposed to change. Human beings are not inherently objective. Making critical observations with well-sophisticated instruments and the reinterpretation of information may lead to changes in theories. (2E-2: *Informed*)
	No… I think knowledge, like theories, does not change. (3E-1: *Naive*)	Theories change as instruments and methods advance. Earlier, people believed the Earth was flat, but now, we know it is round. Scientific works lack perfection or absoluteness. (3E-2: *Informed*)
Scientific Laws Vs. theories	Theories do not exist without law. Theories change into law. (1E-1: *Naive*)	The law is more accurate. Theories change, but laws do not change. Theories develop after experimentation. Example Atomic theories modified. (1E-2: *Transitional*)
	We learn theory in the classroom. (2E-1: *not classifiable*)	They relate in that laws are superior to theories. (2E-2: *Naive*)
	There are many theories and laws in science. Example. Atomic theories and the law of gravity. (3E-1: *Naive*)	Theories develop from hypotheses after testing. Laws are natural and more perfect than theories. (3E-2: *Transitional*)
Social and cultural influence on science	It is not affected by culture and society. (1E-1: *Naive*)	Society and culture affect science. (1E-2: *Transitional*)
	Scientists are human with their own culture. Their work may be affected by their culture. Scientists doing science are neutral. (2E-1: *Informed*)	Society and culture affect scientific research. I think creationist theory in evolution is formulated by religious people who do not accept the theory of evolution. (2E-2: Informed)
	I believe cultures do not affect scientific work. (3E-1: *Naïve*)	Some societies respect their culture and do not accept ideas that contradict it. (3E-2: *Transitional*)
Imagination and creativity in scientific investigation	I think scientists use creativity and imagination in science. Because creativity and imagination are important for doing science. (1E-1: *Transition*)	Imagination and creativity exist in science. For example, the units and constants in science are determined by human convention. They do not read directly from the natural world. (1E-2: *Informed*)
	Scientists do not use creativity and imagination. These make scientific works have biases. (2E-1: *Naive*)	Yes, scientists use creativity and imagination. They are very important. Scientific activities such as observation, interpretation, prediction, and experimental design require creativity. (2E-2: *Informed*)
	In science work, creativity and imagination are not important. (3E-1: *Naive*)	Scientists usually use their creativity and imagination. Not all things in the world are visible. Scientists need to use their creativity in scientific work to explain hidden things and analyze data. (3E-2: *Informed*)

NOS theme	Pre-interview	Post-interview
Methodology of scientific investigation	I think scientists use a single and universal scientific method. (1E-1: *Naive*)	There is no single and universally accepted way to do science. For example, scientists may use inferences and observations to answer their questions. (1E-2: *Informed*)
	Single scientific method. The method must be the same internationally. (2E-1: *Naive*)	There is no single method. The scientific method is one way to do science. In addition to the scientific method in astronomy, scientists often use observation. (2E-2: *Informed*)
	Single universal scientific method. (3E-1: *Naive*)	No single method. Several methods can be used in science. (3E-2: *Transitional*)

Table 5: Representative pre- and post-intervention experimental group interview organized by NOS themes (Source: own interview)

NOS themes	Pre-interview	Post-interview
Observation and inferences	I think it is not the same but different because they use the same instrument. (1C-1: *Transitional*)	It is different because. (1C-2: *Transitional*)
	The same, if different, they do not find the same result. (2C-1: *Naive*)	I think they will make the same observations and draw the same inferences. (2C-2: Naive)
	Scientists observe and infer the same phenomena in different ways because they are brilliant in scientific work. (3C-1:Transitional)	I hope it will be different because they are different people with different backgrounds and abilities. (3C-2: *Informed*)
Tentativeness of scientific theories	Theories change. For instance, in biological science, theories of abiogenesis are changing. (1C-1: *Informed*)	Theories change. The theory of abiogenesis changed in biology. (1C-2: *Informed*)
	Theories do not change. This is because they are constructed based on accurate experiments. (2C-1: *Naive*)	Theories must not change. Scientific knowledge must be accurate. I believe they are tested for certainty. (2C-2: *Naive*)
	I know knowledge changes. Thus, scientific theories might change. (3C-1:*Transitional*)	Scientific theories change. (3C-2:Transitional)
Scientific Laws Vs. theories	I am not able to differentiate these two terms (1C-1:Not classifiable)	Ok… theory means not well tested, but law is tested. (1C-2: *Naive*)
	Laws are more truthful than theories. (2C-1: *Naive*)	Theory and law possess a hierarchical structure. Theory becomes law with sufficient evidence. (2C-2: *Naive*)
	Theories and laws are scientific knowledge. Laws are more realistic. (3C-1: *Naive*)	Theories are constructed, but Laws are discovered. (3C-2: *Transitional*)
Social and cultural influence on science	Sure, culture and society influence. Scientists may have a hidden interest in promoting their religion, culture, and politics through science. (1C-1: *Informed*)	Culture and society affect science. They affect science by affecting scientists' work and explanations. (1C-2: *Informed*)
	Science is not free from the influence of society and culture. (2C-1: *Transitional*)	No, they do not influence science, because science is about nature. (2C-2:Naive)
	Societal culture affects scientific research. Society may distort scientists' work to serve its own interests. (3C-1: *Informed*)	Yes, it affects. Cultural values and religions affect the acceptance of scientific works. For example, religious people do not accept evolutionary theory. (3C-2: *Informed*)
Imagination and creativity in scientific investigations	I know scientists must be creative. This must be used in science. (1C-1:*Transitional*)	They must be used. Creativity and imagination are important for scientific investigation. (1C-2: *Transitional*)
	Creativity and imagination are human elements. They must not be used by scientists. (2C-1: *Naive*)	I think creativity and imagination are important for science, and they must be used. (2C-2: *Transitional*)
	Scientists should not need to use creativity and imagination. These events make scientists biased. (3C-1: *Naive*)	Using creativity and imagination should be practiced in science. (3C-2: *Transitional*)
Methodology of scientific investigation	Single scientific method. It helps to avoid biases. (1C-1: *Naive*)	Single scientific method. The method must be the same internationally. (1C-2: *Naive*)
	Single scientific method. In different science subjects, I learned the scientific method to do science (2C-1: *Naive*)	Single Universal scientific method. To find reliable results, the scientific method must be used. (2C-2: *Naive*)
	Single scientific method. A common method of doing science. (3C-1: *Naive*)	Scientists may use different types of methods. (3C-2: *Transitional*)

Table 6: Representative pre- and post-intervention control group interview organized by NOS themes (Source: own interview)

DISCUSSION

An informed understanding of NOS is vital for scientific literacy and a focal point in most science education reform documents (Abell & Lederman, 2007). Additionally, science educators are reminded that grasping NOS concepts is crucial and forms part of their teaching competencies. Herman and Clough (2016) emphasized the necessity for science teachers to possess a deep understanding of both scientific content and NOS to effectively teach science. Thus, nurturing NOS understanding among PSSTs requires attention and collaborative strategies. This study evaluated the impact of explicit SPS instruction on NOS understanding. Our findings from prior intervention assessment of NOS in indicated NOS conception in PSSTS are not at an adequate level in the overall and specific themes of NOS as presented in various previous literatures (Abd-El-Khalick & Akerson, 2004; Liang et al., 2009; Cofre et al., 2019; Mesci, 2020; Zion et al., 2020; Wang et al., 2023). They held less informed conceptions in observation and inference, the tentativeness of scientific theories, social and cultural influences on science, imagination and creativity in scientific investigations, uninformed conceptions of laws vs. theories, and the methodology of scientific investigation. In line with our findings, laws vs. theories and methodologies in scientific investigation were also reported as naïve NOS themes in PSSTs by different researchers (Miller et al., 2010; Cofre et al., 2019; Gizaw et al., 2024 (in press)).

The prevailing perspective on the NOS holds that inferences and observations differ, and that two scientists may not perceive or interpret the same object or phenomenon in identical ways (Liang et al., 2008). This disparity is largely attributed to the subjective nature of scientists and variations in their prior knowledge and perspectives. However, many students and teachers hold the misconception that scientists maintain objectivity and perceive and interpret phenomena uniformly (Jaina et al., 2013). In this study, exposing PSSTs to explicit instruction on Science SPS facilitated the development of a scientifically accepted view regarding observation and inference within NOS themes. Both observation and inference are fundamental components of both SPS and NOS. The observed enhancements in the NOS theme of observation and inference may be attributed to the PSSTs' clear comprehension of these skills through explicit SPS instruction. During explicit SPS skill instruction, several PSSTs were encouraged to observe and infer the same phenomena and share their observations and inferences with their peers. It is expected that the disparities encountered when comparing their observations and inferences with those of their peers contributed to their improved understanding of this NOS theme.

Liang et al. (2008) highlight the inherent tentativeness in scientific theories and knowledge, stemming from advances in data collection and analysis tools, the introduction of new techniques, and the reinterpretation of existing data. Despite this scientific understanding, many teachers and students maintain contradictory beliefs. Research indicates a prevalent belief that science offers definitive explanations supported by facts and evidence, leading to a deep-seated conviction among students and teachers (Jaina et al., 2013). In our study, the tentative nature of scientific theories and knowledge emerged as a significant strength of the NOS. Through explicit SPS instruction, PSSTs engaged in various scientific activities, such as observing the same event or object with different instruments (e.g., naked eye, hand lenses, compound microscope), analyzing identical data independently, and repeatedly drawing conclusions or interpretations. PSSTs were encouraged to discuss the origins and implications of inconsistencies among their findings. It is anticipated that the discrepancies and dynamic nature observed in their work contributed to an enhanced understanding of the tentativeness of scientific theory or knowledge within the NOS theme. Observation serves as a means to gather information, data, or evidence in the process of scientific knowledge production. Changes in observation methods can sometimes alter evidence or data, potentially challenging well-established knowledge. Our study demonstrates that these scientific phenomena can be effectively conveyed to PSSTs through explicit SPS instruction.

According to proponents of the consensus view of the NOS, such as Kampourakis (2016), both theories and laws constitute bodies of knowledge. Laws are discovered while theories are invented; both are subject to change, with neither being inherently superior to the other, and theories often elucidate laws. However, PSSTs struggle to grasp these distinctions and similarities between theories and laws. One prevalent misconception among PSSTs, as established by Cofre et al. (2019), is the belief in a hierarchical structure where theories are deemed superior to laws, and theories evolve into laws with sufficient evidence. This misconception was evident in our study samples, with many PSSTs failing to clearly differentiate between these two bodies of knowledge. Moreover, the distinction between law and theory constitutes a challenging aspect of the NOS for our PSSTs, as evidenced by their lack of understanding and limited improvement following SPS instruction. Our findings align with previous research indicating the difficulty of altering PSSTs' conceptions regarding the NOS law-versus-theory theme. For example, Mesci and Schwartz (2017) found that, despite enrolling in NOS and scientific inquiry courses delivered through explicit and reflective approaches, several PSSTs still struggled to distinguish between scientific theory and law. However, contrary to our findings, Cofre et al. (2019) reported, based on a review of seven studies focused on changing PSSTs' NOS conceptions, that the law-versus-theory aspect was the most improved in four studies.

As a human endeavor, science is influenced by the society and culture in which it is practiced (Liang et al., 2008). Cultural values, political systems, and expectations shape how and what science is conducted and how it is accepted. Contrary to this, there are views among some PSSTs that science is free from political, social, cultural, and religious influences (Cofre et al., 2019). Regarding this theme, most of our PSSTs held a more transitional view. Improvements in PSSTS cultural and societal influences on NOS occurred after intervention through explicit SPS instruction, but these were not significant. Consistently, Mesci and Schwartz (2017) found that PSSTS struggle to improve their culture and society's influence on NOS themes after enrolling in an explicit, reflective-based NOS and scientific inquiry course. Moreover, Cofre et al. (2019) outlined the social and cultural embeddedness of science as one of the difficult aspects of NOS for change. Contrary to our finding, studies generally indicate that explicit-reflective and context-based instructions improve NOS conception of PSSTs, including cultural and societal influences on science. For instance, Bell et al. (2011) found that elementary PSSTs' NOS understanding improved when NOS instruction was grounded in a global climate change context and in a stand-alone topic.

Scholars contend that scientists employ their creativity and imagination in formulating hypotheses, crafting theories to elucidate natural phenomena, and making predictions during their scientific inquiries (Erduran & Dagher, 2014). However, many studies show that many teachers and students hold the belief that there are no human elements, such as creativity and imagination, in science (Abd-El-Khalick & Akerson, 2004; Liang et al., 2009; Mesci, 2020; Zion et al., 2020; Wang et al., 2023). Although the majority of our participants acknowledge the presence of human elements in science, some maintain an alternative viewpoint, denying their existence. Our intervention, implemented through explicit SPS instruction, led to significant changes among PSSTs in our sample regarding the recognition of imagination and creativity in scientific investigation. During the intervention, students engaged in activities such as object classification based on criteria, data collection through measurements, and data analysis and interpretation. The impact of these SPS was evident in the post-interview responses, in which participants in the experimental group provided justifications and examples. For instance, two participants from the experimental group responded as follows: "*For example, measuring units and constants in science come from human creativity through convention. They do not read directly from the natural world (1E-2: Informed)", "All things in the world are not visible. Scientists need to use their creativity in science work to explain hidden things and analyze data (3E2- Informed).*" Cofre et al. (2019) highlighted in their review that imagination and creativity in scientific investigation are among the aspects of the NOS that are easily influenced by educational interventions.

Scientists employ various methods such as observation, classification, mathematical deduction and induction, inference, speculation, and experimentation to address inquiries and amass scientific knowledge (Erduran & Kaya, 2018). Consequently, there is no single, universally accepted, step-by-step, one-way to do science. However, prior research has revealed a misconception among PSSTs that scientists strictly adhere to a singular, universal, step-by-step scientific method (Cofre et al., 2019; Zion et al., 2020). This misconception was also prevalent among the participants in our study. Both qualitative and quantitative data from our study indicate that the PSSTs in our sample harbored naive conceptions regarding the methodology of scientific investigation within the NOS theme. However, after participating in the intervention, the experimental group demonstrated a significant improvement in their understanding of the methodology of the scientific investigation NOS theme. This improvement might be attributed to the fact that most SPS can serve as methodologies for scientific investigation. The intervention provided students with opportunities to practice accumulating scientific knowledge without strictly adhering to step-by-step scientific methods, simply by making observations, inferences, and predictions. According to Cofre et al. (2019), the methodology of scientific investigation is among the most challenging NOS themes to change in PSSTs. However, in our study, this theme showed significant improvement due to the intervention.

CONCLUSION

Improving PSSTs' understanding of NOS is essential for effectively imparting science content and NOS concepts to their students. In our study, we examined the level of NOS conception and the impact of explicit SPS instruction on various NOS themes among PSSTs. Our findings revealed that NOS themes, such as observation and inference, the tentative nature of scientific theory and knowledge, the role of creativity and imagination in scientific investigations, and methodologies in scientific investigation, were significantly enhanced through intervention via explicit SPS instruction. SPS and NOS themes are intricately linked; they share associations and overlap. It is anticipated that these connections facilitate the transfer of knowledge and skills acquired by PSSTs through explicit SPS instruction to NOS conception themes. Our study demonstrated that explicit SPS instruction can provide a more effective framework for context-based NOS instruction. Therefore, by incorporating explicit NOS instruction into the PSST curriculum, there is potential to foster both the development of SPS and understanding of certain NOS themes among PSSTs. The NOS themes of law vs. theory and of cultural and social influences on science did not show significant change as a result of our intervention. It indicates that interventions aimed at improving NOS themes need to create tailored opportunities that directly address specific NOS themes. A single strategy may not be sufficient for all NOS themes. Therefore, we recommend that strategies utilized for enhancing NOS understanding should encompass all NOS conception themes to be effective.

DECLARATIONS AND STATEMENTS

Data availability statement

The original raw data used to draw the conclusions of the investigation are available from the corresponding author upon request, without undue reservation.

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Ethical approval

All Procedures performed in studies involving human participants were in accordance with the ethical standards of the institution's research committee and with the 1964 Helsinki Declaration and its later amendments. Participants of the study were informed before enrollment about the objectives and the usage of the information they provided. Moreover, the data analysis was conducted in accordance with research ethics.

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Author contributions

Corresponding author involved in the conceptualization, selecting methodology, making analysis, producing visualization, and writing the original draft preparation. All other authors read the original drafts and gave constructive comments.

Conflict of interest

The authors declare the study was undertaken without any authoring, commercial, or financial relationships that could raise a potential conflict of interest.

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Full research paper

ARTIFICIAL INTELLIGENCE LITERACY AND ANXIETY LEVELS OF PRE-SERVICE SCIENCE TEACHERS: A MIXED METHOD STUDY

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ABSTRACT

The study aimed to assess levels of "artificial intelligence literacy" (AIL) and "artificial intelligence anxiety" (AIA) among pre-service teachers and to examine their relationship. The study used an explanatory sequential design, a mixed-methods design. Quantitative data were collected from 136 pre-service teachers using the "Artificial Intelligence Literacy Scale" and "Artificial Intelligence Anxiety Scale" through convenience sampling. Qualitative data were collected through semi-structured interviews with nine pre-service teachers using criterion sampling. Quantitative data were analyzed using ANOVA and correlation analyses, while qualitative data were subjected to content analysis. The results indicated that pre-service teachers' AIL levels did not differ significantly by GPA, AI knowledge level, or emotional state towards AI. However, they varied significantly by skill level with technological tools.

Additionally, AIA levels did not differ significantly by skill level in using technological tools or AI knowledge level. However, they varied considerably based on GPA and emotional state variables. Correlation results revealed no significant relationship between AI levels and AIA levels. The qualitative data from interviews supported the quantitative results, indicating no relationship between AIL and AIA levels. As a suggestion, training can be provided to increase pre-service teachers' awareness of AI.

KEYWORDS

Artificial intelligence anxiety, artificial intelligence literacy, pre-service teachers

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Highlights

- *It was determined that pre-service teachers' artificial intelligence literacy was close to high, and their anxiety levels towards artificial intelligence were at a medium level.*
- *It was observed that there was no significant relationship between pre-service teachers' artificial intelligence literacy and their anxiety towards artificial intelligence.*
- *Semi-structured interviews with pre-service teachers supported the quantitative result that there was no significant relationship between AI literacy and AI anxiety.*

INTRODUCTION

Artificial intelligence (AI) technology has been used in various fields, including transportation, health, agriculture, and banking. It has now also become integrated into the learning and teaching process, playing a role in education (Demir & Güraksın, 2022). Integrating AI applications in educational environments offers several advantages, including making learning more effective, personalizing teaching to accommodate individual differences, and facilitating quick feedback for evaluation purposes (Chiu et al., 2023). These AI applications in education are seen as an opportunity, and their significance grows as technology advances. Teachers and pre-service teachers need to keep up with current technological applications to adapt to the changing student profiles driven by technological development and evolution (Hussin, 2018). Digital and technology literacy concepts have gained attention, emphasizing the importance of people having the skills to reliably and effectively use digital resources to access information (Kaya Özgül et al., 2023). Technology literacy involves understanding and using technology correctly and evaluating its effects (Ejikeme & Okpala, 2017).

On the other hand, artificial intelligence literacy, first mentioned in 2015 (Konishi, 2015), refers to the ability to effectively and efficiently use and understand artificial intelligence technologies and to critically evaluate their potential effects (Long & Magerko, 2020). Artificial intelligence literacy is believed to become more important than digital and technology literacy due to its impact size and potential (Çelebi et al., 2023). Therefore, being AI-literate individuals plays a significant role in effectively using this technology, which we are increasingly in close contact with.

It is important to note that pre-service teachers need to develop artificial intelligence literacy, considering the continuous development of technology. This is crucial as they will encounter AI applications in their professional and daily lives (Laupichler et al., 2022). However, it is worth noting that there are few studies on AI literacy, and those that exist are still in their early stages (Laupichler et al., 2022). These studies include review studies (Çelebi et al., 2023; Laupichler et al., 2022), case studies (Lérias et al., 2024), test development studies (Hornberger et al., 2023), studies focusing on the development of AI literacy (Kong et al., 2022; Kong et al., 2024), and studies that have created comprehensive evaluation frameworks (Wang et al., 2023). Most of these studies use qualitative research methods or aim to develop artificial intelligence literacy, underscoring the need for further research in this area (Schiavo et al., 2024). One specific area that requires more attention is anxiety research related to artificial intelligence. The relationship between artificial intelligence (AI) literacy and AI-related anxiety among pre-service science teachers is both significant and complex. AI literacy has been found to correlate with lower anxiety levels. In other words, individuals who have a strong understanding of AI tend to feel more confident when using technology. This, in turn, reduces fears of becoming obsolete or feeling inadequate in the face of AI advancements (Ayduğ & Altınpulluk, 2025). Research by Ayduğ and Altınpulluk (2025) found that Turkish pre-service teachers with higher digital literacy reported lower levels of AI anxiety, suggesting a predictive relationship in which greater literacy can alleviate anxiety to some extent.

Furthermore, discussions about AI in educational settings have shown that when pre-service teachers learn about generative AI, their anxiety towards these technologies notably decreases. This underscores the role of familiarity in reducing apprehension (Bae et al., 2024). Therefore, educational interventions aimed at enhancing AI literacy could be a key strategy in alleviating anxiety among future educators, thereby fostering a more positive attitude towards integrating AI into the classroom (Eyüp & Kayhan, 2023).

When reviewing the literature on artificial intelligence anxiety, various groups have been included in the studies, such as health professionals (Filiz et al., 2022), candidates of different professions (Takıl et al., 2022), nurses (Seren Intepeler et al., 2022), dentists (Bulut et al., 2024), private hospital employees (Şeker et al., 2024), randomly reached individuals (Kazak, 2023), tourism workers (Çetiner & Çetinkaya, 2024), university students (Aytaç, 2022; Gültekin et al., 2022; Kaya, 2023; Aktaş Reyhan & Dağlı, 2023), teachers (Özdemir, 2023; Sevimli Deniz, 2022), public employees (Şen, 2024), and accounting professionals (Özbek, 2024). Additionally, Schiavo et al. (2024) examined the relationship between artificial intelligence literacy, anxiety, and acceptance among participants of different ages, education levels, occupations, and nationalities. Notably, a mixed-methods study evaluating the literacy-anxiety relationship among pre-service teachers has not been found. Therefore, this study is expected to address this gap in the literature and provide guidance for future research. The study aims to assess the levels of artificial intelligence literacy and anxiety among pre-service science teachers and to explore the relationship between these two variables. To achieve this aim, the study sought answers to the following questions:

1. What is the artificial intelligence literacy level of pre-service science teachers, and does this level differ significantly according to the variables of GPA, artificial intelligence knowledge level, skill level of using technological tools, and emotional state towards artificial intelligence applications?
2. What is the level of artificial intelligence anxiety of pre-service science teachers, and does this level differ significantly according to the variables of GPA, artificial intelligence knowledge level, skill level of using technological tools, and emotional state towards artificial intelligence applications?
3. How do pre-service teachers with different AI literacy levels differ in their anxiety toward artificial intelligence?

METHODS

Research model

This study used a mixed-methods approach, combining quantitative and qualitative methods. The idea behind mixed-method research is to leverage the strengths of one method to compensate for the weaknesses of the other (Cresswell & Plano Clark, 2018). Employing multiple data collection methods, known as data triangulation, is crucial for enhancing the validity and reliability of the findings. While data triangulation demands more time and effort from the researcher, it significantly contributes to the depth, credibility, and generalizability of the research results. Given the multidimensional and complex nature of events and phenomena, employing multiple methods to understand them holistically is undeniably beneficial (Yıldırım & Şimşek, 2021).

The study employed an explanatory-sequential design, progressing from quantitative to qualitative data collection and analysis. The researcher then integrates the data from both stages to interpret how qualitative data explains quantitative data (Cresswell & Plano Clark, 2018). In the quantitative phase, the study collected data through survey research to reveal specific characteristics of the group (Büyüköztürk et al., 2013). This phase focused on examining the artificial intelligence literacy and anxiety levels of pre-service teachers across various variables. In the qualitative phase, the study utilized a case study approach to deeply examine and analyze specific situations, environments, or programs (Büyüköztürk et al., 2013). Interviews were conducted with selected pre-service teachers based on the quantitative results, using a semi-structured interview format prepared by the researchers.

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Working group

The quantitative study group was formed during the 2023-2024 academic year at the Faculty of Education Science Teaching Department in a province in the Marmara region of Turkey. All pre-service teachers studying science education at the faculty who volunteered to participate in the study were included in the sample. It consisted of 136 pre-service teachers. The researchers used convenience sampling to select participants, which involves selecting individuals who are readily accessible to the researcher due to time and cost constraints. The main reason for using convenience sampling was the accessibility constraints and exploratory nature of the research. As the scales were administered face-to-face, the most accessible students at the faculty were included in the study. There were time and resource limitations in reaching the target group during the research period. The purpose of the study was explained to the participants, and additional information about the quantitative study group is provided in Table 1.

Questions	Answers	*f*	%
Gender	Woman	114	83.8
	Male	22	16.2
Classroom	1. classroom	34	25.0
	2. classroom	34	25.0
	3. classroom	39	28.7
	4. classroom	29	21.3
Grade point average	4.00-3.50	7	5.1
	3.49-3.00	56	41.2
	2.99-2.50	46	33.8
	2.49-2.00	21	15.4
	1.99-1.80	3	2.2
	1.79 and below	3	2.2
Skill level in using technological tools (computer, cell phone, etc.)	Medium	61	44.9
	Good	60	44.1
	Very good	15	11.0
Whether they have attended any training (course, conference, etc.) on artificial intelligence before	Yes	27	19.9
	No	109	80.1
Level of knowledge about artificial intelligence	Too much	7	5.1
	A little	101	74.3
	Too little	25	18.4
	Less	3	2.2
The feeling that artificial intelligence is becoming more and more present in our lives	Positive emotions	43	31.6
	Undecided	87	64.0
	Negative emotions	6	4.4

Table 1: Demographic information of the quantitative study group (*N* = 136 people).

Most of the quantitative study group (83.8%) consisted of women, with no significant difference in grade level, although the largest group (28.7%) was in the 3rd grade. The overall grade point averages were concentrated in the 3.49–3.00 range (41.2%), with technological tool usage skills at a moderate (44.9%) and good (44.1%), the majority (80.1%) had not received artificial intelligence training and had some knowledge (74.3%) about artificial intelligence, and finally, the majority (64.0%) felt uncertain about artificial intelligence.

The qualitative study group, comprised of pre-service teachers, was selected using criterion sampling, a purposeful sampling technique, for the semi-structured interview as part of the study's objectives. Criterion sampling involves selecting individuals with specific qualifications to participate in the research (Büyüköztürk et al., 2013). -The scores from the "Artificial Intelligence Literacy Scale" and "Artificial Intelligence Anxiety Scale" were used to categorize the pre-service teachers' total scores as "low", "medium", and "high". Subsequently, three pre-service teachers from each category were chosen, resulting in a total of nine participants. Initially, a total of nine pre-service teachers were selected, with three from each level, but throughout the process, data saturation was monitored, and additional interviews were planned if necessary. Further information about the qualitative study group is provided in Table 2.

During the semi-structured interviews with pre-service teachers, there were eight female and one male candidates. Among them, four taught 2nd grade, one taught 3rd grade, and four taught 4th grade. In terms of their proficiency levels, one candidate each had a low level of both AIL and AIA (T1, T2, and T3), two had a medium level of both AIL and AIA (T4 and T5), 1 had a medium level of AIL and a high level of AIA (T6), 1 had a high level of AIL and a low level of AIA (T7), 1 had a high level of AIL and a medium level of AIA (T8), and 1 had a high level of both AIL and AIA (T9).

Teacher candidates	Gender	Classroom	AIL level	AIA level
T1	F	3	Low (L)	Low (L)
T2	F	4	Low (L)	Middle (M)
T3	F	4	Low (L)	High (H)
T4	F	2	Middle (M)	Low (L)
T5	F	4	Middle (M)	Middle (M)
T6	F	2	Middle (M)	High (H)
T7	F	2	High (H)	Low (L)
T8	M	2	High (H)	Middle (M)
T9	F	4	High (H)	High (H)

Table 2: Demographic information of the qualitative study group (*N* = 9 people).

Data collection tools

The study data were collected in two stages: quantitative data in the first and qualitative data in the second. Quantitative data were collected using the "Artificial Intelligence Literacy Scale" (adapted into Turkish by Polatgil & Güler, 2023) and the "Artificial Intelligence Anxiety Scale" (adapted into Turkish by Akkaya et al., 2021). In the first part of the questionnaire, seven questions were prepared: 3 to collect demographic information about the participants and four to collect information about their experiences with artificial intelligence (Gündüz Hoşgör et al., 2023; Polatgil & Güler, 2023). After analyzing the quantitative data, qualitative data were collected through a semi-structured interview form prepared by the researchers. Detailed information on the data collection tools is presented below under separate subheadings: quantitative and qualitative.

Quantitative data collection tools: the AI literacy scale includes four sub-factors: awareness, use, evaluation, and ethics. It consists of two parts: the first includes the personal information of pre-service teachers, and the second comprises 12 items and four factors, including pre-service teachers' views on artificial intelligence literacy. Cronbach's alpha (α) reliability coefficient for the whole scale was found to be .939, .946 for the awareness factor, .989 for the use factor, .988 for the evaluation factor, and.862 for the ethics factor. In this study, the Cronbach's alpha (α) reliability coefficient for the entire scale was found to be .753, indicating high reliability. Pre-service teachers' views on artificial intelligence literacy were evaluated using a 5-point Likert-type rating scale (strongly disagree, disagree, undecided, agree, strongly agree), with responses coded according to the option limits. The respondent can score between 12 and 60 points. Three items need to be reversed: 2, 5, and 11.

The AI anxiety scale also consists of four sub-factors: learning, job change, sociotechnical blindness, and AI configuration. The Cronbach alpha (α) reliability coefficient for the whole scale was found to be .937, .948 for the learning factor, .895 for the job change factor, .875 for the sociotechnical blindness factor, and .950 for the artificial intelligence configuration factor. In this study, the Cronbach's alpha (α) reliability coefficient for the whole scale was calculated as .916, suggesting strong reliability.

Qualitative data collection tools: To investigate the relationship between artificial intelligence literacy and anxiety, a semi-structured interview form was developed, comprising eight open-ended questions based on the items in the sub-dimensions of the artificial intelligence anxiety scale. The questions were finalized based on feedback from experts in science and chemistry education to ensure internal validity.

Data collection

The study data were gathered in a peaceful classroom setting, outside class time, to avoid disrupting their studies.

Quantitative data were gathered over a 25-minute period, with pre-service teachers volunteering to participate.

Qualitative data were obtained through audio recordings with the consent of the pre-service teachers, who were scheduled for semi-structured interviews.

Data analysis

Qualitative data analysis: the quantitative data collected from the AIL and AIA scales were analyzed using SPSS 27.0. To determine the tests to be used for analysis, researchers first examined the normality tests (skewness and kurtosis) for each variable. It was observed that the skewness and kurtosis values for the AILS and AIAS data ranged from -3 to +3 for each variable, indicating a normal distribution (De Carlo, 1997; Groeneveld & Meeden, 1984; Hopkins & Weeks, 1990; Moors, 1986, as cited in Keleş, 2018). Additionally, the homogeneity of variances test results, a prerequisite for the tests, showed homogeneous variances (p >.05). Consequently, researchers employed one-way analysis of variance (ANOVA) and Pearson correlation coefficient as parametric tests.

Qualitative data analysis: Based on the quantitative data obtained, no significant relationship was found between artificial intelligence literacy and anxiety. To examine this situation in greater depth and to support/refute the quantitative results, qualitative data analysis was required. Accordingly, the data obtained through the semi-structured interview form was analyzed using content analysis. Content analysis is a systematic, repeatable method that codes words in a text according to specific rules and groups them into smaller content categories (Büyüköztürk et al., 2013). The views of teacher candidates regarding artificial intelligence were categorized into common themes and presented in separate tables.

Validity and reliability

To ensure the reliability of the data analysis, the opinions expressed by the pre-service teachers were examined by two researchers. Analysis reliability was assessed using the coder reliability formula proposed by Miles and Huberman (2015), yielding 94.1%. Because values above 80% are considered sufficient for inter-coder reliability (Miles & Huberman, 2015), the analysis was deemed sufficiently reliable. Data analysis continued until both researchers reached a consensus on all questions. Furthermore, in the findings section, selected quotes from the pre-service teachers' perspectives were included to enhance the study's credibility and coherence.

FINDINGS

Findings from the quantitative dimension

General mean values of pre-service science teachers' AILS and AIAS scores

The average total scores of 136 pre-service teachers on the AILS were 43.14 with a standard deviation of 4.363, while their total scores on the AIAS were 48.45 with a standard deviation of 9.575. The conclusion drawn was that the pre-service teachers exhibited high levels of artificial intelligence literacy, approaching the "agree" option. However, their anxiety levels were found to be concentrated in the "undecided" option and at a moderate level.

Findings from the ANOVA test according to the independent variables of pre-service science teachers' scores from the AILS and AIAS

The results of the ANOVA test, conducted according to the independent variables, are presented in Table 3 for the scores obtained by the pre-service science teachers from the AILS and AIAS.

Scale	Variable	Variance source	Sum of squares	*df*	Mean square	*F*	*p*	η^2
AILS	General grade point average	Between groups Within groups Total	169.223 2401.122 2570.346	5 130 135	33.845 18.470	1.832	.111	
	Technological tools usage skill level	Between groups Within groups Total	261.842 2308.504 2570.346	2 133 135	130.921 17.357	7.543	< .001	.102
	Knowledge level	Between groups Within groups Total	147.583 2422.763 2570.346	3 132 135	49.194 18.354	2.680	.050	
	Emotion state	Between groups Within groups Total	80.223 2490.123 2570.346	2 133 135	40.111 18.723	2.142	.121	
AIAS	General grade point average	Between groups Within groups Total	1026.091 11349.549 12375.640	5 130 135	205.218 87.304	2.351	.044*	.083
	Skill level in using technological tools	Between groups Within groups Total	336.291 12039.349 12375.640	2 133 135	168.146 90.521	1.858	.160	
	Knowledge level	Between groups Within groups Total	8.692 12366.947 12375.640	2 133 135	4.346 92.985	.047	.954	
	Emotion state	Between groups Within groups Total	10193.172 11282.467 12375.640	2 133 135	546.586 84.831	6.443	.002*	.088

Table 3: ANOVA test results for independent variables.

Significant differences were found between groups in the technological tool usage skill level variable in AILS and in the overall grade point average and emotional state variables in AIAS [$F = 7.543$; $F = 2.351$; $F = 6.443$, $p < .05$]. Since the calculated effect sizes ranged from 0.06 to 0.14, they were considered of medium magnitude (Büyüköztürk, 2011). The Scheffe test revealed significant differences in favor of those with good ($\bar{X} = 44.10$) and very good ($\bar{X} = 45.33$) skill levels compared to those with medium skill levels. In the emotional state variable, significant differences were found in favor of those with positive emotions compared to those with neutral emotions ($\bar{X} = 50.38$). The Bonferroni test revealed a significant difference in favor of those with a grade point average in the 2.99-2.50 range compared to those in the 1.99-1.80 range ($\bar{X} = 50.80$) [$F = 2.351$, $p < .05$].

Findings on the relationship between the scores obtained from the AIL and AIA scales

Pearson correlation analysis was performed to examine whether there was a significant relationship between the scores of the pre-service teachers from the AIL and the AIAS.
No significant relationship was found between AILS and AIAS ($r = -.113$, $n = 136$, $p = .191$). It can be said that approximately 1% of the variability in pre-service teachers' concerns about artificial intelligence can be explained by the artificial intelligence literacy variable ($R^2 = (-.113)\ 2 = .01$).

Findings from the qualitative dimension

Semi-structured interviews were conducted with nine pre-service teachers selected based on the quantitative results. The responses to the interview questions are provided below:

The findings from the pre-service teachers' perspectives on the question "Does learning to use artificial intelligence applications/products make you anxious? Why?"

The subcategory with the highest frequency was "no," while the subcategory with the lowest frequency was "somewhat." These findings are presented in Table 4.

Findings obtained from pre-service teachers' thoughts on the question "How comfortable do you feel about artificial intelligence technologies?"

The subcategory with the highest frequency was "I do not feel very comfortable", while the subcategory with the lowest frequency was "I feel a little uncomfortable". The findings regarding the pre-service teachers' thoughts on the question are presented in Table 5.

Subcategory	Code	f	%	Sample Student Statements
No	Helping/facilitating	4	44.44	*"I would like to learn more applications. It can be more useful for me (T5)."*
	Arousing curiosity	1	11.11	*"It gives me hope. We are gradually being translated into such a phase. I think there is nothing to worry about. It would be professionally beneficial, it is an interesting, beautiful, curious feeling (T1)."*
	Narrow field of use	1	11.11	*"It is not very necessary for me because I do not do anything related to the field of use too much (T7)."*
Yes	Lack of motivation	1	11.11	*"I would feel very relaxed. Buying things ready-made might not satisfy me for long. It is more enjoyable to access information by researching it myself. I use it when I already have an urgent job. Otherwise, I prefer doing my own research. If I know too many applications, it would make me cumbersome and lazy (T3)."*
	Superficiality	1	11.11	*"It makes me lazy that way. When I do it from the book, I wonder about other things in more detail. I think you focus on something more limited there (T4)."*
A little bit	Safety and ethics	1	11.11	*"A little bit…You know, there's talk about whether it will take over our lives? Will it take over our professions? For example, helping with homework… In the future, I will not know whether the students do it themselves or whether they get help from artificial intelligence (T6)."*

Table 4: Pre-service teachers' thoughts on learning to use artificial intelligence applications/products.

Subcategory	Code	f	%	Sample Student Statements
I don't feel very comfortable	Safety and ethics	1	11.11	*"The fact that computers are talking among themselves…It needs to be used carefully An article, for example. Artificial intelligence may pretend to be its own words and may actually be entering into the ethical principles in an article (T9)."*
	Lazy thinking	1	11.11	*"It's not so much for me, but it stresses me that we use it as the whole world. People no longer have their own opinions. No one has an opinion. With artificial intelligence, it's like everyone speaks the same language. Different thoughts will not emerge. We can stop using our brains (T5)."*
	Taking away people's jobs	1	11.11	*"Robots can take people's jobs. Of course, this worries me a bit. Especially jobs that require manual dexterity (T8)."*
	Security	1	11.11	*"It's like they're going to take us over. When I question this, yes, I feel stressed, but it's not something I normally think about. There are good uses and bad uses for weapons, and the same goes for technology. You know, because I think it will be misused. It will not always go well (T4)."*
	Superiority	1	11.11	*As robots increase, people get nervous. Only that part worries me too. Other than that, of course, I think that science constantly makes our lives easier (T2)."*
	Similarity to human characteristics	1	11.11	*"I think it has very scary dimensions. There are artificial intelligences that speak like humans. After a while, they can replace humans in a way. That's why it scares me (T3)."*
Feeling uncomfortable	Lack of information	2	22.22	*"I feel uncomfortable because I can't use it right now. I don't make an effort for it. I don't see such an effort from the school. So I feel uncomfortable right now, but this is completely related to the lack of training. I would be very happy if I could use it and learn its logic and functioning (T1)."*
A little bit feels uncomfortable	Lack of relevance	1	11.11	*"I'm not involved enough to bother too much. I am not very interested. I don't do much (T7)."*

Table 5: Pre-service teachers' comfort level with artificial intelligence technologies.

Findings obtained from pre-service teachers' thoughts on the question "What do you think about the effects of artificial intelligence technologies on society?"

Among the findings from the pre-service teachers' thoughts about the question, the most frequent category was "positive-negative effect". In contrast, the least frequent categories were "helpful/facilitating" and "no idea"; the findings are presented in Table 6.

"Do you have any concerns about whether artificial intelligence technologies will take away people's jobs? Why?" question, and the findings obtained from their thoughts on the question

Among the findings from pre-service teachers' thoughts on the question, the most frequent subcategory was "can replace certain professions". In contrast, the subcategory with the lowest frequency was "cannot replace any profession," and the findings are presented in Table 7.

Category	*f*	%	Sample Student Statements
Positive-negative impact	5	55.56	*"I think it makes society lazy. For example, making him do his work. Making a student do his homework prevents him from learning information and limits his own research. Doing our work with artificial intelligence can reduce socialization. It can reduce your circle of friends. It makes you lonely. There are also positive aspects. Saving time, easy access to information (T6)."*
Assistant/facilitator	2	22.22	*"I think it makes people's lives easier. Robots do things with less effort than humans. We can use artificial intelligence applications that they can use (T8)."*
No idea	2	22.22	*"I live in a small town, there's nothing there. Not many people know much. So I may not know much. Some of my friends use it for lessons, that I know as much as I know (T5)."*

Table 6: Pre-service teachers' opinions on the effects of artificial intelligence technologies on society.

Subcategory	Code	*f*	%	Sample Student Statements
Specific occupation profession can take its place	Robotics	4	44.44	*"They can do people's jobs better. For example, when something is missing, they correct it with feedback. This is difficult with humans. But they can be corrected by writing code. Of course, not in every field. You can benefit in a field like medicine, but it cannot completely replace a doctor because they have no sense of compassion. It thinks like a computer (T9)."*
	Assistant/facilitator	1	11.11	*"We can integrate. We can learn, develop ourselves, and work together. I don't think it can completely take over. In health, for example, there is talk of doctors performing surgery, but can this extinguish the doctor's profession? I don't think it can; it just helps. What it does is reduce the workload of the doctor, but I don't think it completely ends the doctorate (T6)."*
All occupation profession can take its place	Continuity/efficiency Technological development	1	11.11	*"Human power is slower, more limited. It is not artificial intelligence in this sense. Let's think like this. In the past, for example, a shoe used to be processed for days. Now, the factory, o, ne, er day, millions are produced. A teacher can teach 7-8 hours a day at most, but artificial intelligence is unlimited (T2)."*
	Ease of access	1	11.11	*"Since technology is also developing, as long as every student has a computer, a phone, etc., we can learn everything from there. With artificial intelligence, they can learn, find, and do everything. So we may not be needed (T5)."*
		1	11.11	*"You know, they use such coding and artificial intelligence that after a certain point, the need for human beings may no longer exist (T3)."*
No profession has its place, can't take	Feeling numb	1	11.11	*"I don't think there will be much of a problem because they don't have human feelings. Because they are emotionless (T7)."*

Table 7: Pre-service teachers' opinions on whether artificial intelligence technologies will take away people's jobs.

"Do you have any concerns or fears about humanoid artificial intelligence techniques/products (e.g., humanoid robots)? Why?" question, "Do you have any concerns or fears about humanoid artificial intelligence techniques/products (e.g., humanoid robots)?

In the findings obtained from the pre-service teachers' thoughts about the question, the subcategory with the highest frequency was "there is", while the subcategories with the lowest frequency were evaluated as "there is some" and "there is for the future", and the findings obtained are given in Table 8.

"Do you have any concerns/fears about the artificial intelligence technique/product getting out of control/failing? Why?" question, and the findings obtained from their thoughts on the question

The findings from the pre-service teachers' thoughts about the question showed that the most frequent subcategory was "there is", while the subcategory with the lowest frequency was "there is not". The findings are presented in Table 9.

Subcategory	Code	*f*	%	Sample Student Statements
There is	Misuse	1	11.11	*„I'm worried because of the possibility of human substitution. If used for evil purposes, it could lead to disasters if they fall into the hands of bad people. War or something (T3)."*
	Capacity width	1	11.11	*„I am worried. I can worry even when I see it, and he can think what we can't think. In other words, he can know everything. He has the potential to do everything (T5)."*
	Capturing humanity	1	11.11	*„I remember Sofia the robot. It scares me when I think about it. It is like they will take over humanity (T4)."*
	Similarity to human characteristics	1	11.11	*„I'm worried. He's human, and he does all the things we can do. This scares me a lot. I think it can replace humans (T9)."*
	Autonomy	1	11.11	*„I'm worried. They can hurt us because the people who manage them are the ones who design them in the first place. But then they manage them with their own equipment. They may be unpredictable (T2)."*
No	Helper/facilitator	1	11.11	*„I don't have any worries. I am emotionally neutral. It just makes people's work easier. I think positively, mostly because it makes people's lives easier (T8)."*
	Not witnessing negativity	1	11.11	*„I don't have any attachment. I am neutral. I did not see anything very negative (T7)."*
There are some	Sameness/normality	1	11.11	*„So I'm a bit worried. There could be unity among them. Creating one kind of human being. Because the personality traits of humanity are different, but the traits we attribute to them could be the same. They are all hardworking, they are all lazy... One type of person (T6)."*
There is for the future	Potential to multiply in numbers	1	11.11	*„I don't have any worries or concerns in the current way. They are few in number now, so I'm not afraid. We can't produce many of them because they are very expensive and don't have many functions. What are we going to do with it? There are too many people. There is no need. If their numbers increase, they will be smarter and more emotionless than we are. Therefore, they can do anything (T1)."*

Table 8: Pre-service teachers' opinions on humanoid artificial intelligence techniques/products.

Subcategory	Code	f	%	Sample Student Statements
There is	Failure to intervene	2	22.22	*"I would probably get stressed. I can't intervene anyway; that would stress me out. What to do when it gets out of control is also important. It depends more on the function of the product you use (T3)."*
	Disruption of work	1	11.11	*"So the robot can do a job wrong or make it very bad. Or a malfunction can disrupt a job. If it gets out of control, the work is disrupted. It takes time to fix it (T8)."*
	Ethical breach and security	1	11.11	*"The use of the photograph elsewhere scares me. Computers doing something in the background also scares me (T9)."*
There are some	Security	2	22.22	*"If it gets out of control, it can lead to war. Therefore, it gives me some anxiety (T5)."*
	Spread of misinformation	1	11.11	*"Well, for example, people may be accepting information as correct only through artificial intelligence right now. For example, when there is a malfunction, it may accept false information as true for everyone (T5)."*
No	Mediocrity/simplicity	1	11.11	*"I don't have too many worries since I see it as if it is a bit more like an electrical breakdown (T7)."*
	Controllability	1	11.11	*"What can robots do? I think I can manage it. It cannot take over and do anything because it is in my hands to manage it (T4)."*

Table 9: Pre-service teachers' thoughts about the artificial intelligence technique/product getting out of control/failure.

"Do you have any concerns/concerns that the artificial intelligence technique/product may lead to robot autonomy? Why?" question, and the findings obtained from their thoughts on the question

In the findings obtained from the thoughts of pre-service teachers about the artificial intelligence technique/product leading to robot autonomy, the subcategory with the highest frequency was "there is", while the subcategory with the lowest frequency was evaluated as "there is some", and the findings obtained are given in Table 10.

Findings obtained from pre-service teachers' thoughts on the question "What do you think about the present and future of artificial intelligence technologies?"

The findings from pre-service teachers' thoughts on the question showed that the highest frequency was "positive-negative effect", followed by "wide usage area" and "gradual progress". The findings are presented in Table 11.

Subcategory	Code	*f*	%	Sample Student Statements
There is	Failure to control	3	33.33	*"It scares the hell out of me. That's actually my concern about artificial intelligence. It's scary if they get out of control rather than if they take over. Without being able to intervene. Because we also do it ourselves. We write the code. They will be a problem for us (T9)."*
	Security and numbness	2	22.22	*"I mean, he can do anything. It can take over everything. When there is human intervention, at least it can stop somewhere. But when it does everything on its own, it can take over our lives. I might be worried about security. Its numbness is also very important. It has no sense of pity (T5)."*
	Security and interference in human life	1	11.11	*"Yes. Security, and also, for example, if there is interference in human life, I mean, a person does not want interference by another person, which is never wanted by a robot (T2)."*
No	Technology is not yet developed	2	22.22	*"I don't think it's developed yet. The robot is a human being. I don't think such a thing can happen yet unless that person installs that program (T6)."*
There are some	Technological error/flaw	1	11.11	*"I might have some concerns. Because inevitably, people may not think the same. You program the robot, and then it starts working on its own. But there may be a bug in that device, there may be something wrong. Can perceive (T8)."*

Table 10: Pre-service teachers' opinions on whether the artificial intelligence technique/product will lead to robot autonomy.

Category	*f*	%	Sample Student Statements
Positive and negative impact	3	33.33	*"They are constantly evolving. New features are always being added. So maybe they are working on things that we can't predict right now. Even though it seems under control now, I'm still worried it will get out of control in the future. It's good for today, It is fun. But it is worrying in the future (T9)."*
Vitality	2	22.22	*"When we look at it in general, it is quite advanced now, but I feel that in the future, all jobs will turn to artificial intelligence. I think it will be everywhere in our lives, whether it is robots, I think it will be everywhere in our lives (T5)."*
Development/ progress	2	22.22	*"Right now, I think we are progressing very well. I don't think it's that good in our country. I can say it is as good as it can be. But for example, we see very good progress abroad. I hope it will progress more in the right way. So I think it needs to progress. I think it will progress a lot in the future. I can't think 10, 20, 30 years from now, it will progress a lot. I think it will progress more than I can imagine. I think it will be like in the movies. (T1)."*
Wide area of use	1	11.11	*"I think it will progress a little more. It is coming to life more in terms of robots. I don't know what makes our work easier, especially in industrial areas, such as the whole university, workpiece assembly, and painting. I think that robots like robots do the job (T8)."*
Progressive progress	1	11.11	*"It is developing, it will develop even more. I think we can continue our lives together by being intertwined; it can't replace us. I guess I can't think about the future yet because we are trying to keep up with what is coming out now, or we haven't fully integrated them into our lives. I think we can't integrate the new ones without integrating them. So I think it will happen slowly. It has to come into our lives. Development is instantaneous, but our use of it requires a certain process (T6)."*

Table 11: Pre-service teachers' thoughts on the present and future of artificial intelligence technologies.

Integrating quantitative and qualitative data

Based on both quantitative and qualitative data, no significant correlation was found between pre-service teachers' artificial intelligence literacy and their anxiety about artificial intelligence. To gain further insights, semi-structured interviews were conducted with nine pre-service teachers. The results of these interviews are presented below:

The responses to the question "Do you have any concerns or anxieties that artificial intelligence technology/products could lead to autonomous robots?"

The findings from the responses of prospective teachers with varying artificial intelligence literacy and anxiety levels are presented in Table 12.

Quantitative result	Qualitative working group	Sample Student Statements
$r = .113$ $p = .191$ $p > .05$	LLLA	*"I don't have a fear as it is now, I might have a fear if their numbers increase. If their numbers increase, they will be smarter and more emotionless than we are. So they will be able to do. They can do it. I think a little more about the security part. I don't have any concerns other than security (T1)."*
	LLMA	*"Yes. Security, and also, for example, if there is interference in human life, I mean, a person does not want interference by someone else, which a robot would never want (T2)."*
	LLHA	*"There is. There are sci-fi movies about a world ruled by robots. I think we can kind of head towards that because I don't see how we can think humanely anymore. If we can produce, if robots have an idea, they may want to get rid of us, or I don't know, different things (T3)."*
	MLLA	*"Yes, if I am in control, if he is in control, he cannot be stopped (T4)."*
	MLMA	*"I mean, he can do anything. It can take over everything. With human intervention, at least, I mean, you can stop somewhere, but when you do everything on your own, our lives could be in danger. I might be nervous about security. The numbness is also very important. There is no sense of pity (T5)." Our lives could be in danger. I might be nervous about security. The numbness is also very important. There is no sense of pity (S5)."*
	MLHA	*"I don't think it's developed yet. The robot is also a human being. Unless that human installs that program, I don't think it can happen yet. So right now I do not have a concern (T6)."*
	HLLA	*"Maybe, but here's the thing. Because it's a human being who made it, you know, how much can he get out of the way? I am not sure about that (T7)."*
	HLMA	*"I might have some concerns. Because inevitably, one may not think the same. You program the robot, and then it starts to work on its own, but there may be a fault in that device; it may detect something wrong (T8)."*
	HLHA	*"It scares the hell out of me. That's actually my concern about artificial intelligence. From their takeover without being able to… It would be much more frightening if they got out of control than if they took control. Without being able to intervene… Because we also do it ourselves. We write the code. They will be a problem for us (T9)."*

Table 12: Pre-service teachers' opinions on whether an AI technique/product will lead to robot autonomy, by AI literacy and anxiety level.

The pre-service teachers' responses to the question showed similarities, with both anxious and non-anxious individuals across various literacy levels. These findings are consistent with the quantitative results ($r = .113$, $p = .191$, $p > .05$). Upon analyzing the sample statements, it was evident that pre-service teachers with low AI literacy levels expressed low levels of anxiety (T1), while those with high AI literacy levels exhibited higher levels of anxiety (T9). The scale results indicated that anxious pre-service teachers (T6, T4) expressed differing opinions.

Findings from the thoughts of prospective teachers with varying levels of artificial intelligence literacy and anxiety regarding the question "What do you think about the present and future of artificial intelligence technologies?"

The findings from responses of prospective teachers with varying levels of artificial intelligence literacy and anxiety are presented in Table 13.

Pre-service teachers' views on the present and future of artificial intelligence are similar. Only T2, T3, and T9 pre-service teachers reported anxious thoughts about the future of artificial intelligence, compared with other pre-service teachers. While the future concerns of pre-service teachers with low literacy focused on the increase in the number of humanoid robots and potential security problems, those of pre-service teachers with high literacy were similarly based on the potential for this technology to be used as a security threat. Most pre-service teachers stated that artificial intelligence is developing and will make a name for itself in the future, with many more use cases.

Quantitative result	Qualitative working group	Sample Student Statements
	LLLA	*"Right now, I think we are progressing very well. I don't think it's that good in our country. I can say it is as good as it can be. But for example, we see very good progress abroad. I hope it will progress more in the right way. So I think it needs to progress. I think it will progress a lot in the future. I can't think 10-20-30 years from now, it will progress a lot. It will be like in the movies. I think (T1)."*
	LLMA	*"Today it's fine, but in the future it could get out of hand. There are many, many. If there are too many robots, we may feel strange (T2)."*
	LLHA	*"I think it will continue without stopping, but I think, as with everything else, too much technology is harmful. I think it should be stopped at a point where its advanced dimensions can pose a danger to people. Of course, who will decide that is another issue. But I think it is good as it is now. I don't know how far it will go in the future, but I think replacing people and so on is bad, so I have negative feelings about it. But the possibilities now for facilitating access to information and so on are enough. Overdoing it would be bad (T3)."*
	MLLA	*"In terms of practicalization for our own needs today, we are currently building robots that are being built. Artificial intelligence for easy access to information…But in the future, I think even flying cars, you know. I don't even need a flying car, maybe even higher. Will happen. I think the practices will progress further (T4)."*
r = .113 p = .191 p > .05	MLMA	*"When we look at it in general, it's quite advanced now, but I feel like in the future all jobs will turn to artificial intelligence. I think it will be everywhere in our lives, whether it's robots. (T5)."*
	MLHA	*"It is developing, it will develop even more. I think we can continue our lives together by being intertwined; it can't replace us. I guess I can't think about the future yet because we are trying to keep up with what is coming out now, or we haven't fully integrated them into our lives. We can't integrate the new ones without integrating them. I think. Therefore, I think it will happen gradually. Its entry into our lives or its development is instantaneous, but our use requires a certain process (T6)."*
	HLLA	*"I don't think we've heard a lot of artificial intelligence names before. In the last few years, even artificial intelligence departments have started to open. Has begun. They are trying to develop it. I think it will develop further. We will be very close in the future (T7)."*
	HLMA	*"I think it will progress a little more. With technology and everything, it has 20- 30 years. It comes alive more in terms of robots. I don't know what makes our work easier, especially in industrial areas, all universities, and business. I think robots do work, such as assembling parts and painting (T8)."*
	HLHA	*"They are constantly evolving. New features are always being added. So maybe they're working on things we cannot predict right now. Although it seems under control now, I am worried it will get out of control in the future. It is nice and fun today, but it is worrying in the future (T9)."*

Table 13: the opinions of pre-service teachers with different levels of AI literacy and anxiety about the present and future of AI technologies.

The findings from the thoughts of pre-service teachers with different levels of artificial intelligence literacy and anxiety regarding the question "Do you have any anxiety or fear towards humanoid artificial intelligence techniques/products (e.g., humanoid robots)? Why?"

The findings from the responses to the question by pre-service teachers with different levels of artificial intelligence literacy and anxiety are presented in Table 14.

When analyzing pre-service teachers' opinions, the results align with the quantitative findings (r = .113, p = .191, p > .05), indicating no significant correlation between artificial intelligence literacy levels and anxiety. Some individuals with low AI literacy levels reported low anxiety (T1), while others with high AI literacy levels expressed anxiety (T9). Conversely, some with low AI literacy levels reported high anxiety (T3), while those with high AI literacy levels reported low anxiety (T7). Among the three pre-service teachers with high AI literacy levels, T7 appeared indifferent, possibly due to a lack of experience and knowledge; T8 had positive experiences and an optimistic outlook on artificial intelligence, and T9 expressed concerns about the potential job displacement resulting from the widespread use of artificial intelligence. These observations from pre-service teachers correspond to the quantitative results.

Quantitative result	Qualitative working group	Sample Student Statements
r =.113 p =.191 p >.05	LLLA	*"I don't have any worries or concerns in the current way. They are few in number now, so I'm not afraid. We can't produce many of them because they are very expensive and don't offer much functionality. What are we going to do with it? There are too many people. There is no need. Their numbers will be smarter and more emotionless than ours. So they'll be able to do it (T1)."*
	LLMA	*"I'm worried. They can harm us. Because the people who manage them, first of all, are the people who design them, but then they manage them with their own hardware, or they may be unpredictable (T2)."*
	LLHA	*"I'm worried because of the possibility of human substitution. If used for evil purposes, it could lead to disasters. In the hands of bad people. War (T3)."*
	MLLA	*"Robot Sofia, I remember. When I think about it, it is frightening. Humanity hand in hand (T4)."*
	MLMA	*"I'm worried. I might even be worried when I see it. In terms of knowledge, he can think what we cannot think at that moment. So he can know everything. About everything. Has the potential to do anything (T5)."*
	MLHA	*"So I am a bit worried. It could be them forming a union among themselves. It could be creating one kind of human being. Because the personality traits of human beings may be different, but the traits we attribute to them may be the same. All of them are hardworking, they are all lazy… One type of person (T6)."*
	HLLA	*"I don't have any concerns. I am neutral. I have not seen anything very negative (T7)."*
	HLMA	*"I don't have any worries. I am emotionally neutral. I just want to do. It just makes it easier. I think positively, mostly because it makes people's lives easier (T8)."*
	HLHA	*"I'm worried. He's human, and he does all the things we can do. It scares me. I think it can replace humans (T9)."*

Table 14: Pre-service teachers' opinions on humanoid AI techniques/products by AI literacy and anxiety level.

DISCUSSION

The study examined AI literacy and anxiety levels among pre-service science teachers and explored their relationship using both quantitative and qualitative data collection methods. The findings revealed that pre-service teachers exhibited high levels of AI literacy and medium levels of anxiety; however, no significant relationship was found between AI literacy and anxiety at the expected level. The preliminary findings indicate that AI literacy may operate independently of emotional reactions such as anxiety, highlighting a dynamic that merits further investigation in the context of teacher education. AI literacy among pre-service teachers was not significantly influenced by variables such as GPA, participation in AI education, AI knowledge, or emotional state toward AI. However, those with higher proficiency in technological tools exhibited greater AI literacy. Filiz et al. (2022) found that healthcare workers' levels of AI anxiety were moderate.

Additionally, Şen (2024) stated in their study that public sector employees' levels of AI anxiety were above moderate. Similarly, Ayduğ and Altınpulluk (2025) found that teacher candidates exhibit a moderate level of anxiety. In contrast, Takıl et al. (2022) reported that students in the education faculty had high anxiety about artificial intelligence. The researchers suggested that pre-service teachers with advanced technological skills may have more experience and interest in technology, leading to increased familiarity and curiosity about AI. They also noted that individuals who closely interact with technology and have digital competence tend to internalize AI technologies more easily and exhibit a more supportive attitude towards its advancement. Research suggests that individuals who maintain close connections with others and actively engage with technology, as well as those who stay informed about advancements in the field, are more likely to internalize artificial intelligence technologies. Furthermore, possessing a robust level of digital literacy appears to correlate with a more favorable disposition towards the progression and integration of such technologies (Vu & Lim, 2022; Zhang & Dafoe, 2019).

Additionally, the study by Çoklar and Çalışkan (2019) found a moderate, positive relationship between pre-service teachers' perceptions of ICT competence and self-confidence. Similarly, Dringó-Horváth et al. (2025) found a positive relationship between artificial intelligence literacy and digital competence. Overall, pre-service teachers with advanced technological skills may feel more competent, knowledgeable, and literate about AI, thereby influencing their perceptions and attitudes towards AI.

The study revealed no significant difference in pre-service teachers' anxiety levels regarding artificial intelligence, regardless of their skill level with technological tools or their participation in artificial intelligence training. However, there was a notable difference in anxiety levels based on GPA and emotional state towards artificial intelligence. Pre-service teachers with a GPA between 2.99 and 2.50 exhibited significantly higher anxiety levels compared to those with a GPA between 1.99 and 1.80. Higher-GPA students may possess greater knowledge of artificial intelligence and its potential risks, which may lead to heightened anxiety. Conversely, students with lower academic knowledge may feel less concern or anxiety towards artificial intelligence due to a limited understanding of the technology. However, Batool et al. (2025) found a negative relationship between AI anxiety and academic performance and self-efficacy. In this study, students' experiences and perspectives regarding

AI may vary. Students with high academic achievement may have more confidence in AI technologies. They may also have higher self-efficacy. In this study, most teacher candidates reported having little knowledge of artificial intelligence. All these reasons may explain why the studies produced different results.

Another finding of the study is that those with ambivalent feelings toward artificial intelligence have significantly higher anxiety levels compared to those with positive feelings. Similarly, de Holanda Coelho et al. (2025) found that individuals with a positive attitude toward artificial intelligence experience less fear. It can be said that teacher candidates with ambivalent feelings toward artificial intelligence experience uncertainty about its effects on the present and the future. At this point, teacher candidates who lack sufficient information and awareness may experience dilemmas/uncertainties in assessing the potential benefits/harms of artificial intelligence technologies. This may cause them to harbor more anxiety and worry about artificial intelligence. This emotional dilemma/uncertainty that teacher candidates experience may lead them to feel more anxious about artificial intelligence. Gönüldaş & Gümüşkaya (2022) stated that situations such as uncertainty, fear, and future uncertainty cause anxiety in individuals. Furthermore, the study revealed that there was no significant correlation between the AI literacy levels of pre-service teachers and their anxiety levels ($r = .113$, $p = .191$, $p > .05$). This finding was supported by semi-structured interviews with pre-service teachers of varying literacy levels, indicating that the knowledge they possess about artificial intelligence may not directly influence the anxiety they experience. Semi-structured interviews with nine teacher candidates revealed that their responses to the posed questions aligned with the quantitative results, indicating a lack of a linear relationship between their artificial intelligence literacy and their concerns. While pre-service teachers may possess varying levels of knowledge about artificial intelligence, this knowledge does not necessarily influence their concerns and anxieties surrounding the topic. Additionally, individual differences and experiences with artificial intelligence significantly contribute to these feelings. Anxiety levels tend to fluctuate based on the personal perceptions and attitudes of the pre-service teachers. Consequently, these factors can explain the absence of a meaningful relationship between artificial intelligence literacy and anxiety levels. Moreover, the scale results indicated that teacher candidates displaying both high and low anxiety levels provided responses that contradicted the quantitative findings during the semi-structured interviews. Pre-service teachers might have been in a more positive frame of mind or felt more at ease during the interviews, which could have influenced their answers. Furthermore, some candidates may have internalized their anxiety, hindering their ability to articulate their thoughts clearly and comfortably during the interviews. Interestingly, a study by Schiavo et al. (2024) yielded contrasting results, revealing a statistically significant relationship between all sub-dimensions of AI literacy and anxiety. The authors noted that as participants' AI literacy levels increased, their anxiety towards AI decreased. It is important to consider the demographic characteristics of the sample used in this study, as participants may have had closer contact with AI technologies and greater experience, particularly given their country's technological conditions. This heightened awareness and exposure may have contributed to their more positive attitudes towards AI technologies. Several factors may contribute to the discrepancies between this study and the existing literature. The relatively small sample size and the inability to gather data from science teacher candidates across different universities may have limited the variance needed to identify potential relationships, thus reducing the statistical power of the findings. Additionally, there may be a theoretical explanation for these differences. Cengiz et al. (2025) indicated that this relationship may occur through mediating variables rather than directly, which could explain the absence of a direct correlation in this study. Overall, the lack of a significant relationship observed in this study does not contradict the existing literature; rather, it underscores the complexity of the topic. Future research should explore mediating and moderating variables such as attitudes, self-efficacy, and professional identity, while also examining the subdimensions of literacy and anxiety individually. This approach may facilitate a deeper understanding of how knowledge and perceptions of artificial intelligence interact in teacher education. Most of the pre-service teachers who participated in this study stated that they had not attended any training on artificial intelligence, had some knowledge of it, and had ambivalent feelings towards it. Based on all this data, it can be said that pre-service teachers still need to be closely involved with artificial intelligence technologies. Cengiz and Peker (2025) stated that artificial intelligence technology is still in its infancy and argued that it should be used more frequently to allow its positive effects to be seen and its recognition to increase. Similarly, Hopcan et al. (2024) stated that increased education about artificial intelligence could reduce anxiety and fear about it.

CONCLUSION

The study aimed to assess levels of "artificial intelligence literacy" and "artificial intelligence anxiety" among pre-service science teachers and to examine their correlation. The findings indicated that pre-service teachers' AIL levels were relatively high, while their AIA levels were moderate. Furthermore, no significant relationship was observed between artificial intelligence literacy and artificial intelligence anxiety. These results suggest that pre-service teachers currently lack a close familiarity with artificial intelligence technologies and may not possess sufficient knowledge and experience in this area. Given that technologies and applications related to artificial intelligence have only recently gained prominence, it is natural that pre-service teachers may not yet have extensive experience or awareness of this technology. Therefore, it may be premature to expect pre-service teachers to approach this emerging technology in a conscious, informed, and critical manner, particularly considering their limited exposure to it.

Some limitations of this study are as follows. The first limitation of the study is that the study group was determined using an easily accessible sampling method. However, as mentioned above, the main reason for using easily accessible sampling was accessibility constraints and the exploratory nature of the research. Due to time and resource constraints in reaching the target group during the research period, science teacher candidates studying at the faculty were used in the study. While this situation raises questions about the generalizability of the study's results, we are cautious about generalizing the inferential results to a wider population. Another limitation of the study is that it involved only 3 participants per competency level, raising questions about whether data saturation was achieved. In this study, the interview data reached saturation, and no further interviews were deemed necessary. The inflexibility of the number of interviews may limit the diversity and transferability of the findings.

Furthermore, the failure to specify whether data-crystallization methods were used may undermine the reliability of the findings. It is recommended that researchers monitor data saturation throughout the process, adding interviews as needed and using diverse data sources to refine the findings. In line with the results obtained from the research, the following recommendations can be made:

- The study found that pre-service teachers lacked sufficient knowledge of artificial intelligence during semi-structured interviews. To address this, it is recommended to organize a series of training programs to enhance their understanding of artificial intelligence.
- Furthermore, the research was specifically conducted with pre-service science teachers. To provide a more comprehensive understanding, it is suggested that similar studies be conducted with different sample groups to delve deeper into the issue from a broader perspective.
- In addition to quantitative data, semi-structured interviews were conducted to gather qualitative insights from pre-service teachers. It is proposed that using diverse data collection tools can further enrich the process.
- In future studies, we recommend using probability-based sampling methods to examine similar research questions with stronger inferential power.

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