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Editorial

We are pleased to end another fruitful year by extending our gratitude to our readership in the final issue of 2024. The growing number of followers and the international scope of our journal provide the editorial board with a sense of encouragement and optimism. In order to further enhance the professional standards of our journal, we have implemented changes to our publication policies, effective with this issue. Firstly, the decision was taken to publish articles online first after the full evaluation and proofreading processes. Secondly, in response to the considerable volume of submissions and the interest of our esteemed followers, we have expanded the editorial team. Finally, we have made significant improvements in the infrastructure of our website.

This issue features 11 articles from a range of countries. The articles address a range of key topics, including technology integration, TPACK, Indigenous knowledge, science process skills, critical thinking, e-modules, metacognitive and self-regulatory processes, the natural world, biomimicry, virtual laboratories, socio-humanitarian safety, competence-based approaches, and value. These topics are entirely aligned with the latest developments in science education. It is anticipated that these contributions will advance science and technology education, both in terms of subject matter and methodology and in terms of originality on the global stage. We look forward to receiving original content and works that comply with the TUSED scope framework from our esteemed authors and followers.

We would like to express our gratitude to our esteemed authors, who conduct original research with great dedication and effort. We would also like to acknowledge the invaluable contributions of our referees, proofreading office, and journal staff, whose efforts ensure that our publications meet the highest standards of quality and integrity.

We wish you all a Happy New Year!

Best regards.

Prof. Dr. Salih Çepni

Editor-In-Chief

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Bridging the gap in technology integration in education: An examination of science teachers' competencies and needs

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ABSTRACT
This study investigates science teachers' perceptions of their level of Technological Pedagogical Content Knowledge (TPACK) and the challenges they face in integrating technology into the classroom. Using a case study approach, data were collected through the TPACK scale and semi-structured interviews with 102 science teachers. The results reveal significant deficiencies in teachers' design and proficiency dimensions of TPACK, which impact on their ability to integrate technology effectively. While basic technologies such as smart boards and presentation software are commonly used, the lack of advanced integration is attributed to insufficient infrastructure, inadequate training and limited discipline-specific materials. In addition, dissatisfaction with professional development programs and low levels of technological literacy among students further hinder technology integration. The findings emphasize the need for tailored, practical training programs and improved infrastructure to address these challenges. It also highlights the importance of incorporating student-centered, technology-enhanced learning strategies to promote effective teaching practices. Curriculum revisions, collaborative training programs, and further research into the pedagogical impact of technology integration are recommended.

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Introduction

In recent years, the impact of educational technologies on teaching processes has increased significantly. This development is not merely confined to the digitization of instructional tools but also necessitates a more effective consideration of the relationship between instruction and technology (Angeli & Valanides, 2009; Dinçer, 2021a; Mishra & Koehler, 2006). When examining the applications of technology in education, two distinct concepts prominently emerge: "technology use in education" and "technology integration in education," which are often used interchangeably.

The term "technology use in education or instruction" refers to the deliberate incorporation of technological tools into the learning process to achieve predetermined learning outcomes. This use is typically limited to providing instructional support. For example, using a projector to deliver a presentation during a lesson exemplifies technology use in instruction (Mishra & Koehler, 2006). While this approach aims to visually support the teacher's presentation, it does not represent the effective integration of technology within the pedagogical or content context (Ertmer & Ottenbreit-Leftwich, 2010; Harris & Hofer, 2011; Hew & Brush, 2007). In essence, technology use in instruction treats technology as a supplementary tool without fundamentally altering instructional strategies or methods.

Technology integration in instruction is used to describe the incorporation of technology into teaching processes in a way that is consistent with the pedagogical objectives of the course or program in question. In other words, integration entails not only the presence of technology in the classroom but also its transformation into an integral component of instructional strategies (Dinçer, 2021a; Dinçer & Çengel-Schoville, 2022). This signifies that technology is not merely a tool but rather a fundamental component of the teaching process (Mishra & Koehler, 2006). Effective technology integration necessitates the restructuring of pedagogical strategies and the integration of content knowledge with technology. To illustrate, a teacher adopting a student-centered approach in a science class may utilize simulations or data collection tools for interactive learning or enrich the learning experience through collaborative digital platforms. Such practices exemplify the integration of technology in instruction (López-Nuñez, Alonso-García, Berral-Ortiz, & Victoria-Maldonado, 2024; Ng & Fergusson, 2019). In conclusion, technology integration in instruction can be defined as the balanced combination of technology, pedagogical knowledge, and content knowledge (Dinçer, 2021b; Harris & Hofer, 2011).

The distinction between technology use and technology integration in education has considerable implications for the efficacy of educational processes. The utilization of technology in an instructional context is frequently confined to particular objectives, such as the conveyance of information or the presentation of data in a visual format (Kay & LeSage, 2009; Wiebe, Slykhuis, & Annetta, 2007). In contrast, technology integration in instruction aims to transform teaching strategies and establish alignment between technology and pedagogical content (Mishra & Koehler, 2006). The utilization of technology in an instructional context is often teacher-centered, with a particular focus on providing support for teaching materials (Ertmer & Ottenbreit-Leftwich, 2010). Conversely, technology integration is student-centered and aims to facilitate active student engagement (López-Nuñez et al., 2024). While technology use in instruction does not typically result in a fundamental alteration of the existing pedagogical structure and does not necessitate a direct connection between technological tools and pedagogical content (Dinçer, 2021a; Harris & Hofer, 2011), the integration of technology requires the redesign of pedagogical processes and the seamless incorporation of technology as an integral component (Angeli & Valanides, 2009; Dinçer & Çengel-Schoville, 2022). Finally, while basic technological knowledge is often sufficient for technology use in instruction, technology integration requires teachers to develop competencies in technology, pedagogy, and content knowledge (Dinçer, 2021b).

A review of the literature reveals that the majority of studies investigating the relationship between technology and instruction focus on the use of technology in education. Conversely, studies pertaining to the integration of technology in instructional settings predominantly emphasize the development of models. Regardless of whether the studies examine the use of technology or its integration into the learning process, the majority of them identify several limitations. The most commonly cited challenges are related to hardware and infrastructure constraints, as well as the competencies of teachers and students. In order to address the challenges associated with technology integration in instruction, a number of models have been proposed. Among these, the Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra and Koehler (2006), has gained prominence in the academic literature. The TPACK model is designed to facilitate a productive equilibrium among technology, pedagogical expertise, and content knowledge, integrating these three elements to develop effective pedagogical strategies (Angeli & Valanides, 2013). However, translating this model into classroom practice necessitates not only theoretical understanding but also practical training and hands-on experience (Čipková, Karolčík, Fuchs, & Vaněková, 2024).

The integration of technology into instruction has become particularly significant in the teaching of science, where it facilitates students' understanding of scientific knowledge, visualizes abstract concepts, and supports the development of scientific skills (Jonassen, 1995; Linn, Clark, & Slotta, 2003). This highlights the critical role of the TPACK model in effectively addressing these demands. However, when examining the challenges faced by science teachers in the context of

TPACK, it becomes clear that infrastructure deficiencies, inadequate equipment, limited instructional materials, and a lack of pedagogical knowledge stand out as prominent issues (Ertmer & Ottenbreit-Leftwich, 2010; López-Nuñez et al., 2024). Science teachers frequently report access issues to technological tools such as laboratory equipment, simulations, and data collection devices. These deficiencies restrict their pedagogical practices and negatively impact student learning outcomes (Smetana & Bell, 2012; Tondeur, Van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012). In addition to the commonly cited hardware and infrastructure limitations, curricular constraints and teacher-student competencies pose significant barriers to successful technology integration.

The inadequacy of professional development curriculums with regard to content and methodology serve to compound the difficulties encountered by teachers in the context of technology integration (Čipková et al., 2024; Hew & Brush, 2007). The literature indicates that such syllabus often priorities theoretical knowledge over practical experience (Cheng, Molina, Lin, Liu, & Chang, 2022; Ng & Fergusson, 2019; Sui, Yen, & Chang, 2024). This limitation restricts opportunities for teachers to enhance their TPACK levels, thereby negatively affecting technology integration processes. Furthermore, students' proficiency in technology usage is of paramount importance in the context of instructional processes. Teachers' efforts to integrate technology are frequently constrained by students' inadequate levels of technological literacy. These shortcomings impede the attainment of pedagogical objectives during instructional processes (Dinçer, 2017a; Koehler & Mishra, 2009; López-Nuñez et al., 2024).

Considering the issues outlined above, assessing the TPACK levels of science teachers, understanding how they use technology in their lessons, and identifying the challenges they face in these processes are expected to provide valuable insights for educational policies and professional development programs. Building on this premise, the present study aims to assess the TPACK perceptions of science teachers, examine their practices regarding technology use and integration in instruction, identify the challenges they encounter, and evaluate the quality of the training they have received. In line with this objective, the following research questions are addressed:

1) What are the TPACK perception levels of science teachers?
2) What are the practices of science teachers regarding the use and integration of technology in education or instruction?
3) What are the primary challenges science teachers face when using or integrating technology in education or instruction?
4) What is the level and quality of the training science teachers have received related to educational or instructional technologies?

Methods

The aim of this study was to examine the contexts in which science teachers use and integrate technology in the classroom and the challenges they encounter in these contexts. To achieve this aim, the research method was designed as a case study. Both quantitative and qualitative data were analyzed in the study. To collect these data, a brief interview was conducted with the teachers, during which the purpose of the study was explained. The common and distinct aspects of these two concepts were clarified by sharing documents with the participants about the use of technology in teaching and technology integration in teaching. Subsequently, the Technological Pedagogical Content Knowledge Scale (TPACKS) (Yurdakul Kabakçı et al., 2012) was administered to the participants, followed by interviews with the participants that were recorded. The raw data from the interview recordings were transcribed, and the findings of the study were generated by analyzing these transcriptions in detail.

Participants

Before the study commenced, science teachers from 29 randomly selected secondary schools were briefed on the research process, and teachers who volunteered to participate in the study were identified. The participants of the study included 102 science teachers, with professional experience ranging from 9 to 18 years, consisting of 42 male and 60 female participants.

Data Collection Tools

In case studies, the diversification of data is of paramount importance (Barcın Kara & Kuşdemir Kayıran, 2024). In accordance with the aforementioned, the data collection instruments utilized in this investigation included interview recordings and the Technological Pedagogical Content Knowledge Scale (TPACKS), developed by Yurdakul Kabakçı et al. (2012). During the interviews, the participants were asked the following questions:

1) Would you rate the frequency of your technology use in instruction on a scale from 1 to 5? (1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Often, 5 = Very Often)
2) Would you rate your level of technology integration in instruction on a scale from 1 to 5? (1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Often, 5 = Very Often)
3) Would you say which technologies you utilize in your lessons?
4) Would you describe the tools you utilize to integrate technology into instruction?
5) Would you indicate the reasons for your inability to utilize technology in your lessons or for your failure to fully integrate technology into your instructional practice?
6) Have you received any in-service training on technology use or integration in instruction during your professional career? If so, please provide your views on the content of such training.
7) During your undergraduate education, did you receive any training on technology use or integration in instruction? If so, please provide your views on the content of such training.

The TPACKS is a five-point Likert scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) developed by Yurdakul Kabakçı et al. (2012). The scale comprises 33 items and exhibits a Cronbach's alpha reliability coefficient of 0.95, indicating a high level of internal consistency. The scale comprises four factors. The four factors are as follows: Design (α=0.92), Exertion (α=0.91), Ethics (α=0.86), and Proficiency (α=0.85). The maximum score that can be attained on the scale is 165.00, while the minimum score is 33.00. The participants were divided into three categories based on their scores on the scale: low (below 95.00), intermediate (between 96.00 and 130.00), and high (131.00 or above). For the sub-factors of the scale, the levels were determined as follows: for Design factor, participants scoring below 28.00 were classified as low level, those scoring between 29.00 and 40.00 as intermediate level, and those scoring 41.00 or above as high level. For Exertion factor, participants scoring below 35.00 were classified as low level, those scoring between 36.00 and 46.00 as intermediate level, and those scoring 47.00 or above as high level. For Ethics factor, participants scoring below 17.00 were classified as low level, those scoring between 18.00 and 24.00 as intermediate level, and those scoring 25.00 or above as high level. And last factor which is Proficiency factor, participants scoring below 14.00 were classified as low level, those scoring between 15.00 and 19.00 as intermediate level, and those scoring 20.00 or above as high level. To ensure the validity and reliability of the collected data, the scale's reliability was recalculated by the researcher. The analysis yielded a Cronbach's Alpha coefficient of 0.87, confirming the scale's reliability for this study.

Data Analysis

Since the research involved multiple types of data, both qualitative and quantitative data analyses were conducted. Means, standard deviations, and frequency distributions were calculated for each sub-dimension and the overall TPACKS score, and participants were categorized into low, intermediate, and high levels based on predetermined thresholds for total and sub-dimension scores.

A frequency analysis was employed to assess the self-reported frequency of technology utilization and integration, with participants rating their usage on a scale from 1 to 5.

The qualitative data were derived from semi-structured interviews. The audio recordings of the interviews were transcribed in their entirety and subjected to thematic content analysis. Initial open coding was conducted to identify recurring themes and concepts. Codes were grouped into categories that aligned with the study's research questions, focusing on the following categories; types of technologies used or integrated in lessons; barriers to technology use or integration; training experiences and evaluations.

To ensure consistency in qualitative analysis, another researcher independently reviewed the coding framework. Any discrepancies were resolved through discussion, resulting in an inter-rater agreement of 83.00%.

Finally, the study employed a convergent design, in which quantitative and qualitative findings were analyzed independently and then integrated to provide a comprehensive understanding. The quantitative results from the TPACK scale were used to identify patterns, which were further explored through the qualitative insights from interviews.

Results

The results obtained from the TPACKS administered to the participants to measure science teachers' perceptions of their TPACK knowledge levels are presented in Table 1. Upon examining Table 1, it was determined that 60.78% (*n*=62) of the participants indicated low-level perceptions of the Design factor, 22.50% (*n*=23) reported intermediate-level perceptions, and 16.67% (*n*=17) reported high-level perceptions. It was established that 71.57% (*n*=73) of the participants reported low-level perceptions of the exertion factor, 10.78% (*n*=11) indicated intermediate -level perceptions, and 17.65% (*n*=18) indicated high-level perceptions. Furthermore, 25.49% (*n*=26) of the participants indicated low-level perceptions of the Ethics factor, 31.37% (*n*=32) reported intermediate -level perceptions, and 43.14% (*n*=44) reported high-level perceptions. It was determined that 48.04% (*n*=49) of the participants reported low-level perceptions of the Proficiency factor, 39.22% (*n*=40) indicated intermediate -level perceptions, and 12.75% (*n*=13) indicated high-level perceptions. When examining the overall TPACK score, it was found that 60.78% (n=62) of the participants indicated low-level perceptions, 24.51% (*n*=25) reported intermediate-level perceptions, and 14.71% (*n*=15) reported high-level perceptions.

Table 1

Participants' perceptions of TPACK knowledge levels

	Low			Intermediate			High			Total		
	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd
Design	62	19,87	4,11	23	33,09	3,20	17	44,29	4,10	102	26,92	10,25
Exertion	73	23,97	5,22	11	39,28	3,55	18	53,44	3,84	102	30,83	49
Ethics	26	12,62	1,75	32	19,44	1,45	44	27,86	4,84	102	21,33	7,11
Proficiency	49	9,48	2,38	40	16,20	1,62	13	23,46	1,61	102	13,90	5,22
TPACKS	62	74,40	12,39	25	109,04	9,81	15	143,07	8,69	102	92,99	27,82

In order to evaluate the frequency of technology use and integration in teachers' lessons, participants were asked to rate frequency of their technology use on a scale from 1 to 5; and the findings are presented in Table 2. The results indicate that, with regard to the frequency of technology use in lessons, 5.80% (*n*=6) of the participants reported that they almost never use technology, while 38.20% (*n*=39) reported that they rarely used it. 42.20% (*n*=43) of respondents indicated that they employed technology sometimes, 11.80% (*n*=12) reported often use, and 2.00% (*n*=2) stated that they utilized technology very often. In terms of the frequency of technology integration into lessons, 64.70%

(n=66) of the participants indicated that they almost never integrated technology, while 24.50% (*n*=25) stated that they rarely did so. A further 7.80% (*n*=8) of participants indicated that they occasionally integrated technology into their lessons, while 2.00% (n=2) stated that they often did so, and 1.00% (n=1) indicated that they very often integrated technology.

Table 2

Participants' use of technology and technology integration in their lessons

		almost never	rarely	sometimes	often	very often
Technology Use	n	6	39	43	12	2
	%	5,80	38,20	42,20	11,80	2,00
Technology integration	n	66	25	8	2	1
	%	64,70	24,50	7,80	2,00	1,00

Participants were asked about the types of technologies they use in their lessons, and their responses were coded and categorized. The coding results revealed that participants frequently used presentation devices and software (*f*=96), smartboards (*f*=82), interactive videos (*f*=56), instructional software (*f*=41), experiment kits (*f*=33), simulations (*f*=29), and virtual reality applications (*f*=2) in their lessons. A similar question was asked regarding technology integration, and the coding results revealed that participants frequently used presentation devices and software (*f*=20), smartboards (*f*=12), LMS (*f*=12), and experiment kits (*f*=10).

Participants were queried regarding the underlying reasons for their inability to utilize instructional technologies or to achieve comprehensive technology integration in their lessons. The responses obtained from the interviews were subjected to coding and grouped according to similarity. The coding revealed that the majority of participants identified hardware and infrastructure deficiencies (*n*=94) as the primary reason. Other significant factors included teacher competency (*f*=70), student competency (*f*=68), the incompatibility of the curriculum (*f*=64), and a lack of sufficient content (*f*=42).

The participants were queried as to whether they had undergone training in the utilization of technology or the integration of technology into the instructional process during the course of their professional careers. The results indicated that the vast majority of participants (*n*=99) had attended multiple in-service training sessions on technology use or integration. Upon inquiry regarding their satisfaction with the aforementioned training sessions, the majority of participants (*n*=74) indicated a lack of satisfaction, while a minority (*n*=13) expressed satisfaction. The participants were subsequently queried as to the underlying causes of their discontent with the aforementioned training sessions. The responses indicated that the principal reasons were the unsuitable timing of the sessions (*n*=53), the absence of direct relevance to their teaching subjects (*n*=47), the excessively theoretical nature of the training (*n*=21), and the obligatory nature of the sessions (*n*=3).

The final question posed to participants was whether they had received any course on the utilization or integration of technology in the context of their teacher education. It was determined that 10.78% (*n*=11) of the participants indicated that they had not received such course, 15.69% (*n*=16) reported that they did not recall receiving it, and 75.53% (*n*=75) indicated that they had indeed participated in a course. A total of 75 participants who had received course were invited to indicate their levels of satisfaction with the course they had attended. Among the participants, 65.34% (*n*=49) indicated a lack of satisfaction, 21.33% (*n*=16) reported satisfaction, and 13.33% (*n*=10) did not provide a response. When participants who expressed dissatisfaction (*n*=49) were asked to elaborate on the reasons for their dissatisfaction, the most commonly cited issues were the theoretical nature of the lessons (*n*=31), the lack of content specifically tailored to their subject areas (*n*=26), the inadequacy of the instructors (*n*=21), insufficient lesson duration (n=9), and the low level of students' preparedness (n=3).

Discussion

The literature suggests that participants often exhibit a tendency to present themselves more favorably when responding to self-efficacy measures (Dinçer, 2018; 2019a; Kruger & Dunning, 1999; Rosenman, Tennekoon, & Hill, 2011). This tendency is associated with participants' behavior of giving high scores to avoid being perceived as "inadequate". However, in this study, an examination of participants' TPACK perception levels revealed that, except for the Ethics sub-factor, they rated their TPACK levels as low. The participants' acknowledgement of low TPACK levels may be indicative of their willingness to concede the difficulties they encounter in effectively utilizing or integrating technology in an educational context. This result is consistent with previous studies in the literature that have emphasized the positive impact of teachers' openness about their deficiencies regarding technology and their awareness of these issues (Chai, Koh, & Tsai, 2010; Harris & Hofer, 2011; Kramarski & Michalsky, 2015). Nevertheless, the participants' low performance in the Exertion factor indicates that their positive attitudes are not supported by sufficient effort to integrate technology.

The result that the majority of participants reported exerting minimal effort towards achieving technology integration renders this result particularly noteworthy. This may indicate that, despite their awareness, teachers' lack of sufficient infrastructure and motivation leads to a lack of effort in the technology integration process. Previous studies have indicated that this lack of effort highlights the necessity for comprehensive professional development programs designed to enhance technological pedagogical knowledge levels (Čipková et al., 2024; Ng & Fergusson, 2019). The explicit acknowledgement of these deficiencies by the participants represents a valuable starting point for the development of future instructional programs. As previously observed in similar studies (Angeli & Valanides, 2013; Chai et al., 2010; Tondeur et al., 2012), increasing awareness is considered a crucial instrument for overcoming such challenges and fostering greater effort towards technology integration. This further supports the view that awareness-raising initiatives can make a significant contribution to addressing these issues.

The results of this study regarding science teachers' perceptions of their TPACK levels indicate that inadequacies in technology integration are significant challenges at both perceptual and skill levels. Participants' low averages in the Design and Proficiency sub-factors suggest clear deficiencies in their ability to effectively design instruction utilizing technology. The existing literature highlights that successful technology integration in instruction relies on teachers' ability to combine pedagogical and technological knowledge with effective design skills (Angeli & Valanides, 2013; Harris & Hofer, 2011; Mishra & Koehler, 2006). In this context, teachers' low design skills and self-efficacy perceptions appear to be key factors limiting the effective application of technology use and integration in classrooms. Specifically, participants' low perception levels in the Design dimension indicate a significant lack in adapting instructional materials and processes to technology. Similarly, low scores in the Proficiency dimension reveal that teachers struggle to improve their own knowledge and skills, presenting a fundamental barrier to effective technology integration. Harris and Hofer (2011) emphasize that effective technology integration depends on the ability to blend pedagogical and content knowledge with technology, and such deficiencies hinder this process. A study by Wachira and Keengwe (2011) further highlights similar challenges faced by mathematics teachers, particularly infrastructure and professional support shortages, which negatively affect teachers' perceptions of their own competencies in classroom technology integration.

An examination of the findings regarding participants' use of technology in instruction shows that teachers seldom incorporate technology into their teaching practices. This conclusion is supported by their responses in the Proficiency sub-factor of the TPACKS and their frequent mention of tools like presentation software and smartboards when asked about the technologies they use in instruction. Using technology effectively and integrating it pedagogically is closely tied to teachers' self-efficacy perceptions. Harris and Hofer (2011) emphasize that teachers' success in pedagogical strategies depends on their self-efficacy levels. Mishra and Koehler's (2006) TPACK Model demonstrates that effective integration requires a balance of pedagogical, technological, and content knowledge.

Similarly, Angeli and Valanides (2013) argue that strengthening self-efficacy perceptions positively impacts classroom technology integration.

These results highlight the importance of supportive training programs aimed at enhancing teachers' self-efficacy. It is unlikely for a teacher who perceives themselves as inadequate to frequently use technology in their teaching. Additionally, while basic tools like presentations remain foundational in instructional technology, they are no longer seen as innovations but rather as standard instructional materials in a rapidly advancing world (Ertmer & Ottenbreit-Leftwich, 2010; Ng & Fergusson, 2019). Considering that the use of technology in education is a common practice in developed countries, where research often focuses on technology integration rather than basic use, the limited integration among participants is attributed to their low TPACK perception levels and, consequently, their low knowledge levels. Furthermore, technology integration is inherently a more complex process than basic technology use. For instance, Ertmer and Ottenbreit-Leftwich (2010) emphasize that integration is not merely about using technology but requires pedagogical adaptation, further validating this relationship.

A review of the literature reveals a substantial body of research focused on teachers' ability to use and integrate technology in instruction. Many of these studies highlight teachers' inadequacies in this area (Dinçer, 2018; 2019b). However, identifying the root causes of these inadequacies is crucial for proposing effective solutions. Similar to previous studies (Akram, Abdelrady, Al-Adwan, & Ramzan, 2022; Gesta, Lozano, & Patac, 2023), this study also found that the primary limitation hindering teachers from using technology or achieving full technology integration in instruction is the lack of hardware and infrastructure. This limitation is identified as a significant barrier in nearly every study, either directly or indirectly related to the use of technology in education. For example, the absence of essential technological devices, lack of internet connectivity, or slow internet speeds have been identified as factors that impede the learning processes of both teachers and students (Kay & LeSage, 2009; Lucas, 2020). Moreover, the difficulties associated with hardware and infrastructures extend beyond the mere availability of physical resources to encompass concerns pertaining to the upkeep and modernization of these technologies. This has been underscored in prior research (Hew & Brush, 2007; Li, 2023), thereby reinforcing the conclusions of this study.

The results of the study indicate that the reasons teachers struggle to use or integrate technology in instruction are not limited to inadequate physical infrastructure but also include a mismatch resulting from the lack of appropriate technology-based instructional materials. As emphasized in the literature, technology integration is not merely contingent on the physical presence of devices; it is directly related to the availability of pedagogically adapted content and materials (İnan & Lowther, 2010). This highlights the necessity for technology to be developed not merely as a tool, but as a means of achieving educational objectives (Joshi, 2022; Lim et al., 2023; West & Malatji, 2021).

In previous studies, teacher competency has received relatively less emphasis; however, in this study, it emerged as a significant factor in technology use and integration. Participants identified teacher competency as the second most common reason for their inability to use or integrate technology in instruction, which has been interpreted as being closely related to their TPACKS scores. The participants' self-reported low TPACK levels, combined with their acknowledgment of teacher competency as a limitation, suggest that teacher competencies are insufficient for effectively using and integrating technology into instruction. Teacher competencies regarding TPACK have been widely discussed in the literature (Čipková et al., 2024; Kadıoğlu-Akbulut, Çetin-Dindar, Acar-Şeşen, & Küçük, 2023; Ng & Fergusson, 2019; Sui et al., 2024). However, apart from a few studies, there has been limited focus on understanding the underlying reasons for low teacher competencies (Hew & Brush, 2007; Kadıoğlu-Akbulut et al., 2023; Singerin, 2022). The findings from the interviews suggest that the low competency levels of teachers are associated with the quality of the training they have received. This connection highlights the critical need for more effective and tailored training programs to enhance teachers' competencies in technology use and integration.

Despite the fact that the majority of participants reported having received training on technology use and integration during their teacher education or professional careers, their dissatisfaction with these training programs has been identified as a primary reason for their insufficient competency levels (Čipková et al., 2024; Dinçer, 2019b; Kadıoğlu-Akbulut et al., 2023). A review of the relevant literature reveals that such training programs are often delivered with generic content applicable to all fields, rather than being tailored to specific disciplines (Dinçer & Çengel-Schoville, 2022; Harris & Hofer, 2011). This approach is at odds with the principles of the TPACK model, which underscores the necessity of integrating content knowledge (C) with technological and pedagogical knowledge (TP) to ensure comprehensive success (Angeli & Valanides, 2009; Mishra & Koehler, 2006). Regardless of a teacher's proficiency in utilizing a specific tool, the effective application of such tools within their subject area necessitates the acquisition of specialized knowledge and skills (Shulman, 1986; 1987). To develop these competencies, teacher education and in-service training should move away from generic approaches and towards discipline-specific training (Čipková et al., 2024; Darling-Hammond, 2017; Darling-Hammond et al., 2017; Ng & Fergusson, 2019). Moreover, such programs should not be obligatory or excessively theoretical; rather, they should inspire teachers by integrating practical and hands-on elements (Guskey, 2002). Participants' evaluations of the training they received during their teacher education highlight the importance of trainers being subject matter experts. However, the concept of a subject matter expert in the context of TPACK is not straightforward. For instance, an educator specializing in science teaching may not necessarily be an expert in the use of technology for teaching science. In this regard, it is suggested that such courses be co-taught by both educators with expertise in technology and those specializing in the specific subject area. This collaborative approach would facilitate the delivery of up-to-date tools and methods in alignment with pedagogical practices, making the training more effective and relevant.

Another notable reason why teachers struggle to use or integrate technology in instruction is the competency level of students. This limitation, which has been largely overlooked in previous research, is considered a significant finding. While the teacher's competency in utilizing relevant technology is crucial, it is equally important for students to possess adequate knowledge and skills, as they are the ultimate users of these technologies (Angeli, 2005; Astuti, Arifin, Mutohhari, & Nurtanto, 2021; Dinçer, 2017a; López-Nuñez et al., 2024). A review of the literature reveals that studies examining students' literacy in instructional technologies, particularly computers, have consistently identified low levels of competency among students (Dinçer, 2017a, 2017b; Romanchuk, 2021; Sulistiyarini & Sabirin, 2020). These findings are analogous to those observed among teachers and understood to pose a significant barrier to the successful use and integration of technology in education.

It has been concluded that another factor contributing to the inability to use or integrate technology in instruction is the inadequacy of curricula and the lack of sufficient content. When designing instruction, attention must be paid to all elements of the curriculum. Specifically, using or developing materials solely as tools contradicts fundamental instructional principles. Failing to directly incorporate tools into instruction and provide content is considered a significant barrier.

The research findings reveal that one of the reasons for the inability to use or integrate technology in instruction is the inadequacy of curricula and the lack of sufficient instructional content. In the instructional design process, it is essential to move beyond tool-based approaches and meaningfully integrate these tools into pedagogical and content contexts. As Mishra and Koehler's (2006) TPACK framework suggests, technology should not be treated merely as a tool but as a component that combines content and pedagogy. For instance, Ng and Fergusson (2019) highlight that tailoring such approaches to specific disciplines can yield more effective outcomes for both teachers and students. Similarly, Hew and Brush (2007) emphasize that technological materials in curricula often fail to make a direct contribution to the instructional process, further corroborating these findings. In science education, in particular, materials should not merely function as tools for delivering information but should also serve as resources that facilitate conceptual understanding (López-Nuñez et al., 2024). This shift in material design and application is critical for enhancing the effectiveness of technology integration in education.

It is also crucial to emphasize that curricula should not merely focus on the utilization of technology; rather, they should assume an integrative role within a pedagogical context. The incorporation of technology-enhanced self-regulated learning strategies into the material development process has been demonstrated to have a beneficial impact on learning outcomes for both teachers and students (Sui et al., 2024). However, it has been observed that in the majority of existing curricula, the pedagogical context of materials is frequently disregarded, which constrains the potential of technological tools in the instructional process.

Conclusion

This study comprehensively examined science teachers' TPACK perception levels, their use and integration of technology in lessons, and the challenges they encounter in these processes. The findings revealed that teachers generally have low TPACK perception levels, with significant deficiencies, particularly in the Design and Proficiency sub-dimensions. This indicates that teachers struggle to effectively integrate pedagogical and technological knowledge into classroom practices.

The preference of teachers for the use of only presentation devices and smartboards indicates that technology is not being utilized effectively in the context of instruction. This suggests a tendency among teachers to view technology as a mere tool, rather than achieving a high level of integration within the content context. The prevalence of basic-level technology use and the highly limited integration of technology have been linked to the teachers' levels of competency.

The results of the study indicate that deficiencies in infrastructure and hardware are the primary reasons why teachers fail to use or integrate technology effectively. Issues such as internet connectivity problems, the use of outdated devices, and a lack of diverse materials were found to significantly hinder technology integration. Additionally, the lack of discipline-specific material development in curricula emerged as a factor that prevents the effective use of technology within a pedagogical context.

An analysis of the educational backgrounds of teachers revealed that the training they received was largely theoretical, with limited or no discipline-specific content. This indicates an absence of support for the development of teachers' TPACK levels. Furthermore, the study found that students' low levels of technological literacy also constitute a significant barrier to the integration of technology in instruction. In conclusion, the study highlights the necessity for instructional programs that focus on enhancing teachers' TPACK levels through practical, discipline-specific, and motivational training on technology use and integration in education.

Suggestion

Based on the research findings, the following recommendations are put forth to ensure the effective use and integration of technology in education, as well as for future studies.

To effectively use and integrate technology in instruction, it is recommended:

- to improve infrastructure, particularly in terms of internet access, device renewal, and laboratory technologies, considering the challenges teachers face during the technology integration process.
- that teacher education curricula be revised to emphasize instructional technologies within subject-specific training, with the aim of enhancing TPACK levels for science teachers. Moreover, in-service training programs should be designed to be discipline-specific, practical, and motivational. Such programs should be continuous and regularly updated in order to enable teachers to effectively integrate their knowledge of technology, pedagogy, and content.
- that teacher training programs involve collaboration between technology and field experts. It is anticipated that such collaborative endeavours will facilitate the pedagogical integration of technology and the advancement of teachers' subject-specific knowledge and abilities.

- that instructional materials supporting technology integration should be developed to go beyond mere information delivery. These materials should foster active student participation and encourage conceptual understanding.
- that existing curricula should be updated to integrate technology in alignment with pedagogical goals, transforming instructional strategies and supporting technology use through a student-centered approach.
- to develop student-centered instructional programs aimed at enhancing technological literacy, enabling not only teachers but also students to use technology effectively. This will help improve students' skills in working with digital tools.

For future research:

- Comparative studies are recommended to examine the integration of technology across various disciplines to understand how the TPACK model can be applied in different educational settings.
- To evaluate the sustainable impact of professional development programs, long-term longitudinal research is needed to examine how teachers' TPACK levels evolve over time.
- It is recommended to investigate the pedagogical impact of technology integration across different cultural and regional contexts, exploring diverse approaches and barriers to technology use.
- Comparative studies should assess the effects of various professional development programs—such as applied, theoretical, and discipline-specific models—on teachers' TPACK levels.
- Research is needed to explore how students' technological literacy levels influence teachers' efforts in technology integration, identifying strategies to enhance collaboration between students and teachers.
- In specific fields like science education, studies should evaluate the effectiveness of discipline-specific digital tools (e.g., simulations, laboratory applications). These studies should examine how these tools are used by teachers and their impact on students' learning processes.
- Analyze how teachers with varying TPACK levels differ in their ability to use and integrate technology. Additionally, the impact of these differences on students' academic performance and learning processes should be compared.

Limitations

This study offers valuable insights into the competencies and challenges of science teachers with regard to technology integration, particularly in the context of the Technological Pedagogical Content Knowledge framework. However, it is important to acknowledge certain limitations in order to contextualize the findings and to inform future research.

The study involved the participation of 102 science teachers from 29 middle schools. Although the sample size is sufficient to yield meaningful data, the findings may not be fully generalizable to different educational contexts. It must be acknowledged that the findings may not fully reflect the experiences of teachers in other regions, grade levels, or subject areas.

Quantitative data were collected using self-report scales, which may be subject to social desirability bias. It is possible that participants may have overestimated or underestimated their TPACK competencies or the frequency of technology use and integration.

Although the qualitative data obtained from semi-structured interviews enhanced the findings, the study was based on self-reported perceptions rather than on classroom observations or third-party evaluations. This restricts the capacity to comprehensively elucidate the intricacies of teachers' technology integration practices.

While the study identifies shortcomings in teacher training programs, it does not analyze the specific content or instructional strategies used in these programs. A more detailed analysis of the training materials and methodologies employed could facilitate a more nuanced understanding of the reasons behind the shortcomings of these programs.

The study primarily concentrates on the competencies and experiences of teachers, with a relatively limited examination of student-related factors. Although student technological literacy is referenced, its impact on teachers' integration strategies requires further examination.

It should be noted that the findings are specific to science teachers and may not be applicable to educators in other disciplines. A comparative study across different subject areas could provide a broader perspective on the applicability of the TPACK framework.

It must be acknowledged that the study reflects the technological and pedagogical landscape at a specific point in time. Given the rapid advancements in educational technologies, it is possible that the findings may not fully account for emerging tools and practices.

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The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Data will be made available on request.

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Local and indigenous knowledge (LIK) in science learning: A systematic literature review

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ABSTRACT
This research aimed to analyse the literature regarding Local and Indigenous Knowledge (LIK) in science teaching and learning. This research uses a Systematic Literature Review (SLR) to identify articles focusing on studies regarding LIK in science education. This research explores 52 articles from Scopus and Web of Science published between 2014 and 2023 from various countries. The SLR results show that the number of publications increased yearly. LIK is a recognised research topic in various countries, such as Indonesia, the United States, Canada, Australia, and African countries. The SLR results also show types of LIK consisting of daily lifestyle behaviour, system development in society, and knowledge and practice of investigation by the community. These types related to issues in science issue of climate, ecology, medicinal plants, and astronomy. These issues are studied from the perspective of indigenous knowledge, which is harmonised with modern scientific knowledge. LIK implementation strategies in science learning include community-based and place-based education learning development strategies. Implementation of different strategies is the development of a formal curriculum that accommodates LIK, such as Cross-Curriculum Cultural Priorities, Integration of medicinal plants as important content in K-12 curriculum subjects in the USA, Development of chemistry and physics practicums based on knowledge of indigenous communities and culture, and curriculum development in Traditional Ecological Knowledge (TEK).

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Introduction

Local and Indigenous Knowledge (LIK) comes about as an understanding and philosophy developed by society through a long process of interaction with nature, which is then used to make decisions on fundamental matters (UNESCO, 2018). LIK includes knowledge and practices contextualised by local communities in everyday experiences interacting with nature (Druker-Ibáñez & Cáceres-Jensen, 2022; Sharma & Kumari, 2021). LIK is a comprehensive system of society that includes views, practices, knowledge and guidelines for interacting with nature and can be used as a learning tool and source of knowledge regarding environmental conservation (Demssie et al., 2020).

LIK has an essential role in responding to global challenges through the participation of local communities in the development and application of knowledge in various contexts of challenges that occur in society, such as in the context of climate change challenges (Greenall & Bailey, 2022), ecological issues (Magni, 2017; Nesterova, 2020; Sandoval-Rivera, 2020), overcoming the water crisis and water management (Shahraki et al., 2023), and in the context of conservation of medicinal plant diversity (Ridwan et al., 2023). The participation of local communities in developing their knowledge aims to make the LIK owned by the community relevant to knowledge in modern and formal education. However, the integration of LIK into the education curriculum has yet to be fully implemented. In fact, LIK has not been integrated at all in the education curriculum in several African countries (Njoh et al., 2022), even though LIK in education has benefits and an important role for teachers, students and society.

The integration of LIK in the education curriculum has various benefits, namely helping learners understand their regional context, increasing the sensitivity of pupils, teachers and the community to surrounding environmental problems (Njoh et al., 2022). Integrating LIK can eliminate the gap between LIK and scientific knowledge about the environment in education. It can build collaboration between LIK and scientific knowledge in environmental conservation efforts (Nesterova, 2020). The integration of LIK in education also has an essential role in building and improving sustainable competence in learners (Demssie et al., 2020; Magni, 2017).

LIK has a specific relationship with scientific concepts: physics, biology and chemistry (Imaduddin et al., 2020; Parmin et al., 2022; Sumarni et al., 2016). In science education, LIK related to scientific concepts is used as a learning resource in developing knowledge regarding the relationship between science and societal knowledge (Parmin et al., 2022; Parmin et al., 2019). Furthermore, integrating LIK in science education aims to increase more meaningful science learning (Greenall & Bailey, 2022; R. D. Handayani et al., 2019; Mustafaoglu, 2022). Even LIK in science education becomes a means of developing readiness and improving the skills of prospective science teachers, such as improving science lesson planning skills, reconstruction skills for science teaching materials by paying attention to LIK (Parmin et al., 2022), development of experimental design skills (Parmin, et al., 2019), as well as increasing the skills of prospective teachers in identifying STEM in LIK (Imaduddin et al., 2020).

LIK has a role and benefits in science learning. However, the introduction, exploration and use of indigenous knowledge in learning still need more attention as an essential part of the education system (Demssie et al., 2020). Transmitting local community knowledge through formal schools is rarely implemented because the context presented in class is less relevant to the pupil's situation and local community knowledge (Magni, 2017). Another opinion states that in science education, indigenous knowledge contradicts with scientific knowledge, which needs to be given more attention in the science education curriculum (Kim, 2022; Saputra et al., 2016). The lack of integration of LIK in science learning is due to the lack of teacher ability to align LIK with the learning process in the classroom (Fasasi, 2017).

In its implementation, it is necessary to pay attention to the the curriculum that needs to emphasise the use of local resources by involving local communities (Demssie et al., 2020), strategies learning must emphasise local problem-based learning which is a source of knowledge (Fabra, 2019), and learning must be carried out collaboratively in solving problems and creating projects (Datta, 2018; Demssie et al., 2020). Based on this explanation, science learning that integrates LIK can be carried out using learning models, such as problem-based learning, project-based learning, place-based education, and other models that are relevant according to these aspects. However, using these learning models depends on the form and type of LIK in areas relevant to scientific concepts.

Each region and country have different characteristics according to the local potential in that region and country. Local potential includes regional natural resources, human resources, culture, geographical location and history (Jumriani & Prasetyo, 2022). The local potential of the area is related to the flora and fauna as well as sociocultural aspects of the area (Wilujeng et al., 2020). The diversity of local potential in each country results the differences of local community knowledge. Thus, the type of LIK integration in science learning will vary according to the country's local potential. Based on this, a systematic literature review was conducted on various research results regarding local potential, local community knowledge, and their integration into science learning. This research aims to map the types of LIK in various countries and the integration of LIK in science learning in various countries. The problem formulation studied in this SLR is:

1) What are the research trends on local and indigenous knowledge topics in science learning in various countries in 2014-2023?
2) What types and issues of local and indigenous knowledge are integrated into science concept?
3) What implementation types are local and indigenous knowledge in science teaching and learning?

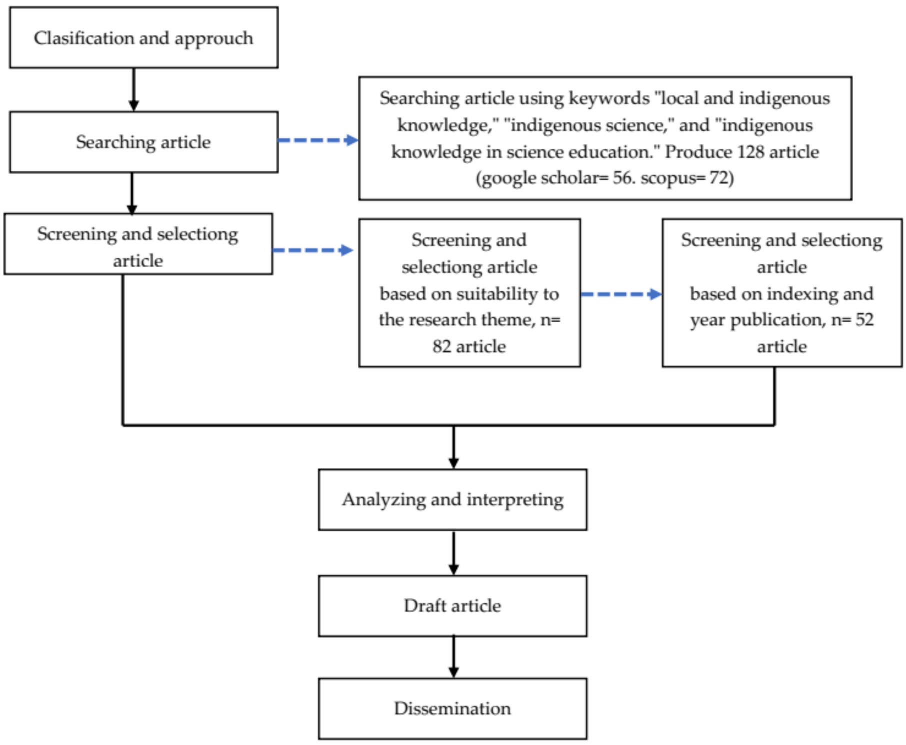
Methods

The research approach used was a systematic literature review (SLR) which aims to obtain data and a description of a variable research explicitly and other esential issues in research (Gough et al., 2019). In a literature review that focuses on the results of research regarding the Local and Indigenous Knowledge (LIK), and the implementation of LIK in science education. A search for articles was carried out using the keywords "local and indigenous knowledge," "indigenous science," “ethnoscience”, and "indigenous knowledge in science education."

The articles collected were sourced from Scopus, WoS, Elsevier, and SINTA. In the process, 52 articles were selected that were appropriate and relevant to the focus of the research study. The SLR process stages were adopted from (Martín-Páez et al., 2019). The SLR stage consists of five stages: classification and approach, searching, screening and selecting, analyzing and interpreting, and the last is dissemination. The following is an explanation of the five stages of SLR.

Figure 1

Stages of the SLR process



In the clarification and approach stages, the researcher determined the focus of the literature review to finding articles related to Local and Indigenous Knowledge (LIK) in science education. The criteria for the specified articles are conformity with the focus of the study (type of the LIK issues context and LIK implementation), and Scopus indexing Q1/Q2/Q3/Q4/internasional indexing/ sinta indexing (grade 1 and 2) with the year of publication 2014-2023.

At the searching, screening and selecting stages, articles about Local and Indigenous Knowledge in science learning were searched through journals in websites such as Scopus, Google Scholar, and Sinta. At this stage, 128 articles were produced based on search results using the publish or perish application. The articles obtained were filtered based on the suitability criteria of the focus of the study, so 85 articles were obtained from the screening results. To ensure the quality and novelty of the articles obtained, the researcher carried out a second screening with indexing criteria and the year of publication so that 52 articles were obtained. The following is a database of the 52 articles analysed in this research.

Table 1

Article database based on indexing

Journal indexing	Name of journal (number of article)	Total of article (%)
Scopus Q1	• Journal of forestry (n= 1) • Cultural studies of science education (n= 5) • Environmental education research (n =1) • Sustainability (n =1) • Research in science education (n= 1) • MAI Journal (n= 1) • Sustainable chemistry and pharmacy (n= 1) • International journal of educational research open (n= 1) • CBE Life sciences education (n= 1) • International journal of science education (n= 1) • Journal of philosophy of education (n= 1) • International journal of disaster risk reduction (n= 1)	16 (30,76%)
Scopus Q2	• Australian journal of indigenous education (n= 3) • Journal of chemical education (n= 1) • Eurasia journal of mathematics, science and technology education (n= 1) • Sage open (n= 1) • Journal of turkish science education (n= 1) • Education sciences (n= 2) • Ecoscience (n= 1) • Acta scienta (n= 1) • Journal of teacher education for sustainability (n= 1) • Diaspora, indigenous, and minority education (n= 1)	13 (25%)
Scopus Q3	• Journal of education (n= 1) • Educational research for social change (n= 1) • Pharmacognosy journal (n= 1) • Chemistry teacher international (n= 2) • Perspectives in education (n= 1) • Case studies in the environment (n= 1) • Universal journal of educational research (n= 2) • African journal of research in mathematics, science and technology education (n= 3) • Waikato journal of education (n= 1) • International journal of innovation in science and mathematics education (n= 1)	14 (26,92%)

Journal indexing	Name of journal (number of article)	Total of article (%)
Scopus Q4	• Ubiquitous learning (n= 1) • Pegem journal of education and instruction (n= 1) • International e-journal of educational studies (n= 1)	3 (5,76%)
Other international indexing*	• Oriental anthropologist (n= 1) • Journal for the education of gifted young scientists (n= 1) • International journal of academic research and reflection (n= 1) • Electronic journal of science education (n= 1)	4 (7,69%)
Sinta indexing**	• Jurnal penelitian dan pembelajaran ipa (n= 1) • Journal of science learning (n= 1)	2 (3,84%)

Note. *articles from these journals are very relevant to the theme. **Indonesian indexing.

In the next stage, researchers analyzed and interpreted data and meaningful information from 58 articles. The data and information analyzed are focused on the research question to obtain conclusions according to the research focus. The analysis and interpretation stage are carried out by providing codes according to the problem formulation, namely types of local and indigenous knowledge and strategies for implementing local and indigenous knowledge in science learning.

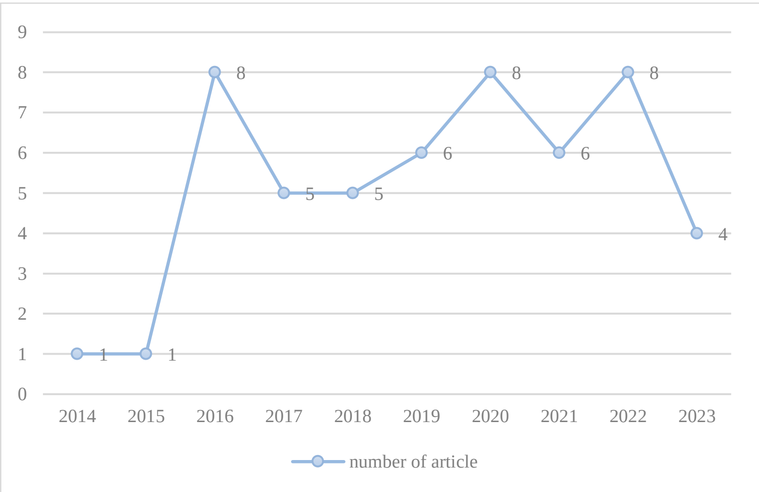
Findings and Discussion

Local and Indigenous Knowledge Research Trends in Science Education

The following representation of literature based on the year of publication within the range of 2014 to 2023 is presented in Figure 2:

Figure 2

Literature representation based on year of publication



Based on Figure 2, research about Local and Indigenous Knowledge in science education over the last ten years has been occurring albeit at a low level. Local and Indigenous Knowledge in each region and country have yet to be fully explored. Furthermore, Local and Indigenous Knowledge has the potential to provide learning that leads to sustainable development so that issues regarding Local and Indigenous Knowledge are still relevant to SDG issues (Demssie et al., 2020). One example of Local and Indigenous Knowledge contributing to ecological challenges includes local community knowledge regarding climate system (Datta, 2018; Magni, 2017).

In another aspect, Local and Indigenous Knowledge research in science education will continue to be an essential study for preparing future generations to face the challenges of global issues. Integrating Local and Indigenous Knowledge in formal education can help develop sustainable skills to face global challenges (Greenall & Bailey, 2022; Sandoval-Rivera, 2020). The diversity of natural resources is one of the essential factors that will make research on Local and Indigenous Knowledge continue to develop. Local community knowledge about the diversity of medicinal plants, the existence of various types of plants, and knowledge about preserving nature and its ecosystems have relevance to science learning in the classroom (Ridwan et al., 2023).

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The representation of literature based on the researcher's country that studies and implements Local and Indigenous Knowledge in learning is presented in Table 2:

Table 2

Literature representation by country

No	Country	N	%
1	Indonesia	12	23%
2	Sout Africa	6	12%
3	Canada	10	18%
4	Ghana	3	6%
5	USA	7	13%
7	Australia	6	12%
9	Mexico	1	2%
10	Argentina	1	2%
11	Taiwan	1	2%
12	Philippines	2	4%
13	New Zealand	3	6%
	Total	52	100%

The mapping results in Table 2 show that Indonesia has the most number of studies examining local and indigenous knowledge in science education (N= 12). Indonesia is a country that has a diversity of local potential, both natural and cultural resources, which can be a source of learning (Sumarni et al., 2022). The diversity found in Indonesia produces various traditions, local wisdom and local knowledge that have been passed down from generation to generation (Diliarosta et al., 2021). This condition makes research on local and indigenous knowledge in Indonesia a widely researched topic in the last ten years, especially in science learning. Several local and indigenous knowledge topics studied in Indonesia include the use of various traditional plants as medicine (Parmin, Nuangchalerm, et al., 2019; Sumarni et al., 2016), traditional scientific processes, such as tradition in making salt manually (Imaduddin et al., 2020), community traditions regarding use bitter melon for breast milk stimulus (Parmin et al., 2022), and use of traditional and natural pesticides (Zidny, 2022).

Canada and the USA are the second and third countries with the most research topics on LIK based on Table 2 (Canada= 10, USA= 7). Several local and indigenous knowledge research topics in the USA are related to environmental issues, such as the principles of indigenous knowledge applied in ecological systems (Verma et al., 2016). Apart from ecological issues, other studies regarding local and indigenous knowledge in the USA relate to local community projects based on STEM about simple technology in ethnomedicine project (Alkholy, 2017). Several African studies are based on the lack of a formal school curriculum that accommodates local and indigenous knowledge (Njoh et al., 2022). In this way, research on local and indigenous knowledge continues to develop, thus strengthening the relevance between local knowledge and modern scientific knowledge.

Issues and Type of Local and Indigenous Knowledge in Science

Local and Indigenous Knowledge (LIK) is closely related to community knowledge about a tradition or phenomenon in their region that is firmly held by the community. This community knowledge is used to solve various problems that occur or as a way of survival and is related to scientific concepts of science. Local and indigenous knowledge consists of 3 types, namely daily lifestyle behaviour, society system, knowledge and practice of investigation by the community with scientific method. Local and indigenous knowledge consists of understanding, skills, and philosophy developed by society (UNESCO, 2018), knowledge and practices contextualised by local communities in everyday experiences (Druker-Ibáñez & Cáceres-Jensen, 2022), and system of society (Demssie et al., 2020). The following is a mapping of the issues and type of Local and Indigenous Knowledge (LIK) in various field of science.

Table 3

Issues and type of local and indigenous knowledge (LIK)

No	Issues of LIK	Scientific field	Description of local and indigenous knowledge	Type of local and indigenous knowledge
1	Climate system	Science education	Indigenous people's style and way of life in maintaining climate stability (McGinty & Bang, 2016),	Daily lifestyle behaviour
			Local people's understanding of land use and the George River as an effort to prevent the negative impacts of climate change (Gérin-Lajoie et al., 2018), community knowledge about forms of adaptation and mitigation disasters in maintaining social-ecological resilience systems as a response to climate change (Tanyanyiwa, 2019), traditional practices and technology of local communities in anticipating climate change (Zinyeka et al., 2016), local community knowledge in seasonal forecasting systems and adaptation to climate change (Mafongoya, 2021), local community knowledge about how to anticipate the impacts of climate change on their communities (Littrell et al., 2020).	System in society
2	Ecology	Environmental education	Understanding of Elders from the Dene First Nation community regarding land-based education (Datta, 2018), local community practices and culture that uphold respect for others and loving the environment (Sandoval-Rivera, 2020), local community ways of life and systems in anticipating environmental degradation (Nesterova, 2020)	System in society
		Science education	Local community knowledge regarding natural resource processing, which focuses on the harmonization of art, science and technology (Govender & Mudzamiri, 2022), local community knowledge regarding river watershed management (Engels et al., 2019), local community knowledge regarding land-based education, both water and land while still prioritising local culture (Jacobs et al., 2021)	System in society
3	Diversity of medicinal plants	Biology education	Research results regarding this type consist of: kind of indigenous traditional medicinal plants to treat wounds, hypertension, anaemia, coughs and colds, and asthma (Bibon, 2022), investigation of indigenous knowledge and values of the traditional martial arts of the Betawi tribe (Indonesia) "silat beksi" is associated with the system motion (Elvianasti et al., 2023).	Knowledge and practice of investigation by the community with scientific value

No	Issues of LIK	Scientific field	Description of local and indigenous knowledge	Type of local and indigenous knowledge
		Science education	Local knowledge about yellow root plant (*Arcangelisia flava Merr.*) contains bioactive compounds which act as antibacterials, thereby inhibiting bacterial growth (Diliarosta et al., 2021), use of bitter melon by local communities as a breast milk stimulus (Parmin et al., 2022), use of various kind of plants in the northern coastal area of Java to treat various diseases (Parmin, Nuangchalerm, et al., 2019), community knowledge about plants used as herbal medicines (Sumarni et al., 2022).	Knowledge and practice of investigation by the community with scientific method
		Chemistry education	Indigenous chemical knowledge in the fields of agriculture, food preservation, food processing, health care and environmental conservation (TAWANDA & MUDAU, 2022), the use of traditional pesticides in maintaining agricultural systems (Zidny, 2022), local community knowledge regarding traditional chemicals used as medicine in aboriginal tribes (Ziebell et al., 2021)	System in society
4	Earth science	Science education	The knowledge of Mäori and other ethnicities in Aotearoa, New Zealand, relates with horoscopes and weather based on people's experience and traditional direct monitoring (Fonua, 2020)	System in society

Based on Table 3, the issues in local and indigenous knowledge generally consists of 4 main issues, namely climate system, ecology, medicinal plants and earth science. The issue of climate change is a global issue. The worldwide community is discussing this issue because everyone worldwide feels the impacts of climate change. Local communities already know the issue of climate system, namely daily lifestyle behaviour and system development in society. The everyday behaviour type is a community lifestyle that has been firmly adhered to and passed down from generation to generation. Research on the issue of climate system states that local communities have knowledge and behaviour that reflect a style and way of life to maintain the stability of climate system (McGinty & Bang, 2016). This community's style and way of life need to be known and reconstructed in the science education curriculum in schools and universities so that the relevance of LIK is established with modern scientific knowledge. Another type of LIK on the issue of climate is system knowledge in society. This type is related to developing systems, tools, and technology by local communities to face and anticipate issue about climate. This type of LIK consists of community knowledge about adaptation systems to face climate issues and the development of simple technology to deal with climate system (Cajete, 2020; José Gérin-Lajoie et al., 2018; Tanyanyiwa, 2019). Another type of system knowledge in society is local community knowledge regarding climate forecasting and mitigation systems in climate (Mafongoya, 2021; Zinyeka et al., 2016). This system in local communities has been proven to maintain regional stability, so it needs to be integrated into modern science learning to be studied scientifically.

Knowledge of ecological issues is essential for society. Local communities already know ecological issues based on knowledge developed from community life practices. In general, research on ecological issues in LIK is a type of system knowledge in society. Systems that have developed in these communities include land-based education systems based on the understanding of Elders from the Dene First Nation community (Datta, 2018), local community systems in anticipating environmental degradation (Nesterova, 2020), local community practice and culture systems in a way that upholds respect and love for the environment (Sandoval-Rivera, 2020). Furthermore, system development in society regarding other ecological issues, namely natural resource processing systems which focus on harmonization of art, science and technology (Govender & Mudzamiri, 2022), river watershed management systems (Engels et al., 2019), systems land and water-based education that emphasizes local culture (Jacobs et al., 2021).

The system regarding ecological issues that have developed in local communities needs to be aligned with the modern science education curriculum. Aligning local community knowledge regarding ecological issues to the science curriculum can develop critical thinking skills to overcome complex environmental problems and maintain environmental sustainability (Datta, 2018; Jacobs et al., 2021; Verma et al., 2016). Furthermore, harmonising indigenous knowledge and Western scientific knowledge about ecology in several research uses term "Traditional Ecological Knowledge" (TEK). Implementation of TEK in some research showed positively impacts to increasing student participation in classroom and enhance students understanding about problems in society (Greenall & Bailey, 2022). Other research shows that integrating TEK with Western ecological knowledge in science learning can contribute to developing sustainable educational paradigms and environmental preservation from the increasingly rapid impacts of climate change (Nesterova, 2020; Sandoval-Rivera, 2020).

Another issue studied in local and indigenous knowledge research is the issue of plant diversity, especially medicinal plants. On this issue, local people know medicinal plants and use them to cure various diseases. This issue of medicinal plant diversity includes the community's knowledge and practice of investigation with scientific value. Local people have searched for and investigated various plants that can be used as medicine for generations. Local people carried out repeated tests traditioally until they discovered the benefits of the plant. In this way, local community knowledge about the diversity and benefits of medicinal plants is used as a learning resource in science learning. In general, medicinal plants are used as exploration material in field project activities to find the relationship between the community's original knowledge about medicine and scientific knowledge (Bibon, 2022; Diliarosta et al., 2021; Parmin et al., 2022; Sumarni et al., 2016). More specifically, in other research, exploration of the benefits of medicinal plants was carried out through laboratory activities to study the content of chemical compounds in certain medicinal plants. Laboratory activities showed relationship between the community's original knowledge and scientific knowledge (Parmin et al., 2022; Ziebell et al., 2021).

Implementation of Local and Indigenous Knowledge in Science Learning

Local and Indigenous Knowledge (LIK) related to problematic issues faced by society can be integrated into formal education through various strategies. The results of a systematic literature review of the articles analyzed show that the LIK integration strategy in science learning uses various implementation strategies, such as developing a curriculum that accommodates LIK and Western science knowledge, developing learning strategies, developing teaching materials, and developing learning evaluation. The following is a mapping of the results of a literature review on articles published in 2014-2023 relating to LIK implementation strategies in science learning.

Table 4

Local and Indigenous Knowledge implementation in science learning

No	Strategy of LIK implementation	Types of implementations LIK and authors
1	Learning strategy development	• Community-based education: a strategy for developing learning and developing scientific knowledge that is based on the knowledge of the people in a community • Place-based education: a strategy for developing learning and developing scientific knowledge that is based on the problems and culture of a particular place (Achimugu et al., 2023a; Baynes, 2016; Bibon, 2022; Cajete, 2020; Cronje et al., 2015; Datta, 2018; Diliarosta et al., 2021; Edson & Nadaraj, 2021; Engels et al., 2019; Fasasi, 2017; Fonua, 2020; Gérin-Lajoie et al., 2018; Hiwasaki et al., 2014; Imaduddin et al., 2020; Jacobs et al., 2021; Mafongoya et al., 2021; Marker, 2019; Mavuru & Ramnarain, 2017; McGinty & Bang, 2016; Morales, 2017; Nesterova, 2020; Elvianasti et al., 2023; Parmin, Fibriana, et al., 2019; Parmin, Nuangchalerm, et al., 2019; Parmin et al., 2022; Rahmawati, 2020; Ruddell et al., 2016; Sandoval-Rivera, 2020; Maren Seehawer, 2018; Sumarni et al., 2022; TAWANDA & MUDAU, 2022; Ugwu, 2018; Vergara, 2022; Verma et al., 2016; R Zidny, 2020, 2022; Robby Zidny et al., 2021; Zinyeka et al., 2016)

No	Strategy of LIK implementation	Types of implementations LIK and authors
2	Curriculum development	• Cultures Cross-Curriculum Priority (Baynes, 2016) • Integration of medicinal plants as an essential content in five subjects in the K-12 curriculum in the USA (Bibon, 2022) • Development of chemistry and physics practicums based on the knowledge of indigenous communities and culture (Achimugu et al., 2023; Mashoko, 2022). • Development of the Traditional Ecological Knowledge (TEK) curriculum (Greenall & Bailey, 2022)
3	Learning material development	• Development of chemistry modules based on the practices of indigenous communities in Australia (Scholes, 2019) • Development of project-based learning modules based on the practices of urban communities and indigenous communities (Hsin & Wu, 2023)

Table 4 shows that LIK in science learning is integrated through the development of learning strategies, curriculum development, and modules or learning materials. The following is an explanation of the implementation of LIK in science learning.

Learning Strategy Development

In the development of learning strategies, the research focuses on developing and implementing learning models or methods by integrating local community knowledge that is harmonized and transformed into scientific knowledge. Based on the results of studies in various literature, the development of learning strategies that implement LIK, namely community-based education and place-based education.

Learning Strategy of Integration Local and Indigenous Knowledge: Community-Based Education

Local or indigenous people have knowledge that is passed down from one generation to the next. Local communities firmly hold this knowledge, known as Indigenous Knowledge or knowledge of native communities (Magni, 2017). Local community knowledge is essential as basic knowledge to preserve culture and pass it on to the next generation (Parmin et al., 2019). However, today, the knowledge of indigenous people needs to be remembered by hegemony and the increasing development of Western or modern knowledge (Greenall & Bailey, 2022; Handayani, 2018; Ruddell et al., 2016). Therefore, various efforts must be made to preserve local community knowledge and reconstruct it in modern science so that all levels of society can accept it.

Local and indigenous knowledge learning strategies that involve local communities are called community-based education (Cajete, 2020; Datta, 2018; Diliarosta et al., 2021; José Gérin-Lajoie et al., 2018; Tanyanyiwa, 2019). During the learning process, students explore the knowledge of indigenous communities related to science concepts to understand science concepts from the perspective of modern science and the community's traditional knowledge. In several studies, indigenous people's knowledge regarding natural science concept issues was reconstructed into scientific knowledge through laboratory activities to confirm the traditional knowledge of the community (Diliarosta et al., 2021; Parmin et al., 2022; Ziebell et al., 2021).

In other research, exploration activities in the traditional knowledge of indigenous people regarding natural science concepts were used as discussion material in class so that students could find harmony between indigenous knowledge and scientific or modern knowledge (Bibon, 2022; Elvianasti et al., 2023; Rahmawati, 2020; Woro Sumarni et al., 2016). More specifically, several studies show that the results of exploring indigenous people's traditional knowledge are used as material for developing STEM learning projects to train creativity and problem-solving (Imaduddin et al., 2020; Woro Sumarni et al., 2022).

Learning strategies that involve local communities are also carried out using community participation and local community leaders. In several studies, the exploration of indigenous knowledge was carried out by directly involving local communities in a participatory way in research projects so that researchers obtained a direct description of indigenous people's practices regarding a context related to the concept of science (Baynes, 2016; Gérin-Lajoie et al., 2018; Sandoval-Rivera, 2020; Seehawer, 2018). The strategy of involving the local community in a participatory manner makes the science concepts learned in class harmonize with the practices of indigenous peoples. Furthermore, the direct participation of local communities also reinforces solving environmental problems by combining traditional knowledge and scientific and modern knowledge.

In another strategy, indigenous people who become community leaders can provide material explanations in the research and learning projects carried out at schools or universities (Alkholy et al., 2017; Bibon, 2022; Datta, et al., 2018). Direct explanations about the practices and knowledge of indigenous peoples from community leaders make learning carried out in class more authentic because it directly presents the people who are considered to have qualified indigenous knowledge. In other settings, indigenous community leaders collaborate with academics in learning that provides traditional and modern perspectives on scientific knowledge and concept being studied to clarify the compatibility between traditional indigenous knowledge and more modern scientific knowledge (Seehawer, 2018; Seehawer & Breidlid, 2021).

Learning Strategy of Integration Local and Indigenous Knowledge: Place-Based Education

Developing other learning strategies as a form of LIK implementation in science learning is carried out by considering the location factor. Indigenous people's knowledge must be connected to where the community grows and develops. Each place has unique characteristics and problems; thus, the knowledge of indigenous peoples that develops also has specificities and uniqueness according to the place. In several studies, the implementation of LIK integration in science learning was carried out by paying attention to the place or known as place-based education.

The implementation of the place-based education strategy is carried out by using local environmental problems to understand science concepts contextually. The ecological problems raised include the quality and quantity of water in a river basin (DAS), used as a context for a group of students developing a water treatment project (Engels et al., 2019). Another problem that is used as a context for place-based education is the land problem. These problematic issues are used as context to understand real problems and bridge indigenous people's knowledge with Western knowledge (Jacobs et al., 2021; Marker, 2019). In general, several studies examining environmental problems around the area aimed to provide direct experience in understanding science concepts contextually, honing problem-solving skills directly, and raising awareness of the importance of ongoing environmental awareness and preservation.

Besides analysing surrounding environmental problems, place-based strategies also use an area's cultural context and local wisdom as one of the strategies for implementing LIK in developing the science concept. In a cultural context, people in one region of Indonesia (the Baduy tribe) can live by applying natural science concepts, such as renewable energy, agriculture, chemical dyes and household chemicals (Zidny, 2021). Other regional cultural contexts linked to the science concept include the movement system by studying the Beksi silat tradition as content and context in science learning (Elvianasti et al., 2023). In several other studies, local culture was explored and developed into science content studied in formal education environments (Bibon, 2022; Dupuis & Abrams, 2017; Sandoval-Rivera, 2020; Scholes, 2019; Vaughn, 2020).

Local and Indigenous Knowledge-Based Curriculum Development

In implementing LIK in science learning, curriculum development is an important part that has yet to be given much attention in several studies on Local and Indigenous Knowledge. In several studies, the development carried out is more focused on preparing LIK to accommodate it in the formal education curriculum. The Australian national curriculum already contains Cultures Cross-Curriculum Priority; thus, in several states, a formal education curriculum has been developed which contains Indigenous Knowledge as a context for studying knowledge and modern science (Baynes, 2016).

In other curriculum developments, the context of medicinal plants is used as an important content in five subjects in the K-12 curriculum in the states of the USA, which were developed as an effort to increase conceptual understanding, metacognitive, science process skills, and increase appreciation of local culture (Bibon, 2022). Other studies have tried to develop a chemistry and physics practicum curriculum by paying attention to the knowledge-based practices of indigenous peoples and their culture (Achimugu et al., 2023b; Kibga et al., 2021; Mashoko, 2022). Furthermore, the LIK integration curriculum development produces a guide for teachers in the learning process that integrates Traditional Ecological Knowledge (TEK) when implementing classroom learning (Greenall & Bailey, 2022).

In general, curriculum development in the LIK implementation strategy is carried out to preserve the community's actual knowledge so that it remains in harmony and can be combined with modern knowledge (Fonua, 2020; Mashoko, 2022; Parmin et al., 2022; Ziebell et al., 2021). In addition, curriculum development related to LIK also aims to increase environmental and cultural awareness among students, teachers, and the community. Furthermore, developing this curriculum is expected to develop LIK as a continuing education effort based on participation and collaboration with the community (Gérin-Lajoie et al., 2018; Nesterova, 2020; Tasingwa, 2019).

Conclusion

The results of a systematic literature review of 52 articles on the topic of Local and Indigenous Knowledge (LIK) show that LIK from 2014-2023 was a viable research topic in science education, LIK issues integrated into science learning include climate system, ecology, diversity of medicinal plants, and earth sciences. These issues are categorised into three types of local and indigenous knowledge: daily lifestyle behaviour, system in society, and knowledge and practice of investigation by the community with scientific method. In each of these issues, local community knowledge is studied from a scientific perspective by reconstructing community knowledge into scientific knowledge. The strategy for implementing LIK in science learning consists of developing learning strategies, LIK curriculum, and LIK-based modules/teaching materials. These results show that LIK is one of the development topics in science education research with a focus on studies, the form of LIK on science education issues and strategies for implementing LIK in science learning. However, to strengthen the relevance of LIK with scientific and modern scientific knowledge, efforts are needed to increase the integration of LIK in science learning, especially in curriculum development for primary, secondary and higher education.

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Didactic student workbook in human anatomy and physiology: Implementation in undergraduate biology education

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ABSTRACT
A didactic student workbook has been used to teach human anatomy and physiology. The didactic workbook has significantly reduced the disparity between teaching materials and students. It accommodated all student learning styles, integrated with *asma al-husna* (the best names are based on the characteristics of God). This workbook also integrates contemplative exercises. The purpose of this study was to investigate the learning outcomes and responses of students after utilizing the didactic workbook in their learning process. The study used a quasi-experimental methodology with a pre-test-post-test control group design. It involved 31 biology education students from UIN Mahmud Yunus Batusangkar. The experimental group was given homework assignments to complete in the didactic workbook, whereas the control group was given the task of summarising and answering the questions in the textbook. Both groups used the discussion method during in-class learning. Essay tests and student response questionnaires were used to collect data. The *t*-test was used to compare the N-gain of learning outcomes between the experimental and control groups. Descriptive analyses were conducted to examine student responses. The didactic workbook was significantly effective ($p<0.05$) in improving learning outcomes compared to the control class. The didactic student workbook was also responded to very positively by students. These findings indicate that a didactic student workbook has the potential to improve learning outcomes and interest in the learning of biology.

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Introduction

Didactic teaching materials facilitate the teaching and learning process (Morales, 2012; Hansen & Gissel, 2017). Didactic teaching materials consist primarily of questions that require various kinds of activities to answer (Hansen & Gissel, 2017). Didactic material has specific aims, student tasks, and measures for evaluation. For example, a workbook and textbook for a specific subject and grade level or a course for a specific topic within a course of study (Gissel & Buch, 2020), can significantly impact students' learning experiences. Didactic teaching materials are equipped with guides for students on how to study learning materials. Though the utilization of didactic teaching materials in learning shows promise for improving learning outcomes, particularly when following established guidelines (Gissel & Buch, 2020; Fernández & León, 2016), more research is required to fully understand the complex dynamics and potential factors that may influence the efficacy of these materials in educational settings.

Human anatomy and human physiology are a compulsory subject in the biology education department of biology, the Faculty of Tarbiyah and Teacher Training, UIN Mahmud Yunus Batusangkar. For decades, textbooks have been the main medium for supporting the teaching and learning of human anatomy and physiology (Chruscik et al., 2022), and there are many good textbooks. Several textbooks provide detailed descriptions of human anatomy (Paulsen et al., 2019), while some focus on realistic illustrations (Thompson, 2015). Detailed and simplified illustrations textbook of human anatomy have been shown to not correlate significantly with learning outcomes because they may not effectively engage students or help them relate the content of the material to their experiences (Lin et al., 2017). This causes a gap between the real life of students and the content of textbooks, thus becoming the main cause of failure of educational institutions in general (Tidon & Lewontin, 2004).

Lieu et al.(2018) and Chruscik et al., (2022) state that textbooks have been the main medium for supporting knowledge of human anatomy and physiology. But often the purpose and effect of educational content in the textbooks used are far from the expectations and interests of learners, leading to student learning difficulties and learning outcomes consequently not match expectations (Chruscik et al., 2022). Almazova, Barinova & Ipatov, (2018) state that students responded very positively to didactic teaching resources in the form of moving picture objects. One alternative is the use of didactic workbooks containing many activities as supplements to textbooks (Marneli, Delfita and Pratama., 2022), including contemplative practice, colouring, completing, contextualising in colour, crosswords, connecting, summarizing a picture, describing processes, sequencing a variety of illustrations and writing the results of contemplation activities. This activity is didactic and supports all learning styles of all leaners (Marneli, Delfita and Pratama., 2022).

Cardoso, Cristiano and Arent, (2009), dos Santos, FS, Guimarães, (2017) and Delfita *et al*.(2020) investigated the effectiveness of didactic teaching materials in increasing student engagement and improving learning outcomes. The teaching materials they used were limited to construct their understanding through drawings and contemplative activities. However, the extent to which didactic teaching materials influence learning and student responses to didactic teaching materials has not been clearly described. This research focuses on learning outcomes and students' learning responses after using didactic workbooks in human anatomy and physiology in undergraduate biology education.

Conceptual Framework of Study

Didactic Teaching Material

Morales (2012) states didactic teaching materials are a group of instructional tools that support the teaching and learning process. According to Fernández & León, (2016), didactic teaching materials include all tools for facilitating the teaching and learning process methodically in an educational setting, as well as for stimulating the senses to aid in the acquisition of ideas, aptitudes, and skills and the development of attitudes and values. dos Santos & Guimarães (2017), Effiong & Igiri (2015), and Stanisavljević et al., (2016) define didactic teaching materials as all tools that help students in contextualising knowledge, filling gaps during learning, facilitate them constructing their scientific knowledge concepts independently, help connect previous knowledge with new knowledge, and develop higher order thinking skills. The authors make it clear that the goal of didactic teaching materials is to facilitate, create, and provide meaning to explanations in order to guide students toward learning, as well as the construction of attitudes and values. This concept captures the overarching goal of education, which is to change society for the better via education. According to

Krista et al., (2016), Chowdhury & Rankhumise, (2022) and Azizah & Nasrudin (2021), the quality of the teaching materials and the use of efficient learning techniques have a direct impact on students' academic achievement.

Didactic teaching resources can be found in a variety of places, including textbooks, websites, and materials created by the teacher. These educational resources include worksheets, workbooks, games, posters, flashcards, and more. Workbook with various pictures are an example of instructional material (Fernández & León, 2016). The teacher gives the students a picture and instructs them to utilise the image to communicate the personal learning objectives. An approach in which a teacher presents pictures to students and asks them to use the pictures as a tool to communicate personal learning goals is a powerful strategy in didactic teaching contexts. Teachers help students to think critically, develop analytical abilities, and connect the material they learn to past experiences and knowledge by allowing them to evaluate visuals and apply them to the topics being studied. This not only improves students' comprehension of the subject, but it also promotes their involvement in the learning process and builds their emotional connection to the information. Thus, using visuals as a communication medium in didactic learning can enhance students' learning experiences and aid in the successful achievement of learning objectives.

Educators generate didactic materials to provide context to their explanations or when they ask their students to do so as part of an activity. The didactic teaching materials packaged in workbook form developed by Marneli, Delfita and Pratama (2022), has questions that require completion with a variety of activities including contemplative practice, colouring, completing, contextualising in colour, crosswords, connecting, summarizing a picture, describing processes, sequencing a variety of illustrations and writing the results of contemplation activities. This activity is didactic and supports all learning styles of all leaners. Beside site, contemplation activities make thinking deep and all-encompassing (Song and Muschert, 2014).

According to Sablić et al. (2015), specifications for didactic teaching materials include several important points. *First*, creating educational materials is not difficult, costly, or excessively time-consuming. Efficiency in creating materials is important for educators to easily access and use them. *Secondly*, effective pedagogical content must be clear, simple, and meaningful for students, ensuring a good understanding of the material presented. *Thirdly*, didactic material must contain information that is valuable, needed, and helpful in the learning process. *Fourthly*, the material must be able to stimulate student interest and motivation, which is an important factor in increasing engagement and desire to learn. *Fifthly*, it is important to ensure that students not only study seriously but also enjoy the material presented. *Finally*, flexibility in educational materials allows for necessary editing to suit learning needs without significant barriers.

Fernández & León (2016) likewise describe several essential qualities of didactic teaching materials. *First*, these materials must be effective, employing diverse examples and engaging activities to convey information. Students should feel comfortable, confident, and personally connected to the subject matter, emphasising its relevance and usefulness to them. *Secondly*, didactic teaching materials should encourage and require independent learning, fostering self-reliance and autonomy among students. *Thirdly*, accommodating various learning styles is crucial, ensuring that all students can effectively engage with the materials. *Fourth*, these materials should stimulate intellectual, artistic, and emotional involvement, triggering both left and right brain activity to enhance learning capacity. *Fifth*, they should not only aid in achieving learning objectives but also nurture positive attitudes and values. For instances, collaborative learning, whether individually, in pairs, or in teams, cultivates a supportive environment where students help each other, work together to accomplish goals, and develop positive attitudes. Additionally, didactic materials play a role in cultivating higher-order thinking abilities, such as problem-solving skills. Explicitness is another essential characteristic, ensuring clarity and transparency in the material's content. *Lastly*, customization and relevance to student specific needs are crucial to effective didactic teaching materials, tailoring the content to resonate with the learner experiences and requirements.

The use of didactic teaching materials promotes students' learning activity and independence (Fernández & León, 2016), helps learners to understand abstract terms in concrete terms, and enhances the integration between cognitive processes and physical manipulation (Politi, 2023). Rosli et al. (2015) note that students who are provided with a stimulating environment rich in preparatory resources, practical teaching methods in mathematics, and a diverse array of materials for reading and writing practice tend to demonstrate better learning outcomes and exhibit higher levels of intrinsic motivation compared to their counterparts exposed solely to traditional teaching methods. Many studies show that the use of didactic teaching materials encourage students' motivation to learn, interest in learning, their independence and other positive attitudes higher when compared to the use of other teaching materials (Milinković & Bogavac, 2011, Utami et al., 2020, Diaz & Woolley, 2015; Tursunovich, 2022).

Construction of Didactic Workbook

A workbook is a book that contains exercises and questions for students and typically includes spaces for their replies. Workbook activities must be in line with the lesson and be directly related to the main content. Using a workbook, teachers may assess their students' learning progress and use the results to decide how best to assist the students moving forward. Workbooks are an excellent teacher's first tool when introducing ways for increasing student enjoyment of learning (Utami et al., 2020).

In this study, "workbook" refers to a book containing exercises and questions designed to facilitate the student learning process in human anatomy and physiology. A workbook contains a variety of tasks that require a variety of student activities including contemplative practice, colouring, completing, contextualising in colour, crosswords, connecting, summarizing a picture, describing processes, sequencing a variety of illustrations and writing the results of contemplation activities (Figure 1). This activity is didactic and supports all learning styles of all leaners.

The didactic workbook also guides students in getting to know verses from the al-Qur'an and *asma al husna* (the best names are based on the characteristics of God) contained in the material. The contemplative element of the teaching materials developed is the existence of contemplative activities that make students directly connected to God and the material at the same time. Material is used as an object of contemplation and (the best names are based on the characteristics of God) is instilled in students during contemplation activities (Marneli, Delfita and Pratama, 2022). Contemplation activities that make the subject matter the object of contemplation make thinking deep and all-encompassing (Song, and Muschert, 2014; Delfita et al., 2020). In conjunction with contemplation, it can promote spirituality as well as self-awareness and compassion (Davidson et al., 2012; Zajonc, 2013; Delfita et al., 2020), boost attention, stimulate the work of the left and right brains (Jha, Krompinger, & Baime, 2007), and enhance metacognitive skills (Zeidan et al., 2010).

This didactic workbook was designed using the ADDIE model (analysis, design, development, implementation, evaluation (Molenda, 2003). In the process of designing didactic workbook is based on reality in the field. Considerations at the analysis stage include the curriculum, competency standards and basic competencies in the human physiological anatomy course, problems found in learning human anatomy and physiology, and student characteristics. The construction of this didactic workbook is grounded in educational and developmental research design (Richey, Klein, & Nelson, 2002). Furthermore, this research adheres to additional criteria; it has undergone a comprehensive process spanning from design activities to assessment and revision. Consequently, the workbook has been developed with logical consistency, aligning expectations with reality (Nieveen, 2007). Formative evaluation was carried out to assess the validity of the workbook developed. Didactic workbooks are designed to bridge the gap between materials and students during learning.

Figure 1

Didactic student workbook

Note. (Marneli, Delfita and Pratama, 2022) Example of didactic workbook constructions. a = cover; b = outline of material and didactic activities for chapter 11 of the respiratory system material; c = introduction to the respiratory system material; d = workbook 11A, activity of completing verses that are scientific signs of the respiratory system; e = workbook 11E, activity of arranging words correctly and then connecting them with lines according to the characteristics of the words that have been arranged, workbook 11F = activity of choosing the right words; f = workbook 11G, conceptualization activity through colouring pictures and finding the *asma al husna* in the picture; g, h and i = contemplation activity.

The feasibility of didactic workbooks is assessed from their validity and practicality. Validity is assessed from the results of expert validator assessments and practicality refers to a systematic evaluation process that focuses on the practical aspects of using these materials in real-world teaching and learning environments biology education students. The validity of the didactic workbook has a value of 3.45 ± 0.43 on a 4-point scale (with 3.20 being 'very valid'), indicating a high level of validity. Similarly, its practicality is rated at 3.32 ± 0.43 on the same scale (with 3.20 being 'very practical'), signifying a high degree of practicality (Marneli, Delfita and Pratama, 2022).

Methods

Research Design

The didactic workbook was trialled on students enrolled in human anatomy and physiology courses during their sixth semester of the Biology study program. Three meetings comprise the online learning process. The respiratory, digestive, and urinary systems' anatomy and physiology are covered in the course content. Before instruction began in the experimental class, students were given the didactic workbook and instructed to complete the assignments in it outside of class. The ensuing assignment was handed in before the lesson started. The discussion method is a learning method that exposes students to a problem. The main purpose of this method is to solve problems, answer questions and understand students' knowledge, and to make decisions. Discussions are more about exchanging experiences to determine certain decisions together. The problems discussed are problems in the workbook. In the control class, students were given a textbook and instructed to create a résumé and answered the questions the textbook. The control class also use the discussion method. A pre-test and a post-test were administered in both classrooms at the beginning and end of each lesson. Additionally, both courses discussed the survey responses from the students. Pre-test and post-test are compared after analysis.

Table 1

Research design

Groups	Pre-test	Treatment	Post-test
Experiment Class	O_1	x	O_2
Control Class	O_3	-	O_4

Note. O_1, O_3 = pre-test; O_2, O_4 = post-test; x = treatment using didactic workbook.

Participants

The participants of this study were biology education students of UIN Mahmud Yunus Batusangkar in the sixth semester of the 2021-2022 academic year. There were 31 students (18 local A students were selected as the experimental class, and 13 local B students were selected as the control class). The experimental class consisted of 16 women and 2 men, while the control class consisted of 13 women. Three meetings were held between biology education students of UIN Mahmud Yunus Batusangkar to evaluate the learning outcome of didactic teaching materials. Responses of students after using the didactic workbook in their learning process were also measured. The student response criteria that are measured are acceptance of teaching materials (satisfaction, awareness, perception, appreciation of teaching materials), learning interest after learning using teaching materials, advantages of teaching materials, and effective in encouraging student interaction.

Instruments of Research

Essay questions (pre-test and post-test) and student response questionnaires about the use of didactic workbooks were used as research instruments. Before implementation, the instruments underwent validation by three validators, an expert in learning evaluation and educational technology. Following validation, it was determined that 8 essay questions for each material to be tested were valid. Additionally, 35 response questionnaire items were declared valid based on the validation results. Instruments that passed validation were then implemented in limited trials in other classes, specifically among Biology Education Students, UIN Mahmud Yunus Batusangkar in the Sixth Semester, Class C. The results of the essay tests were analyzed for the question items, resulting in the identification of five questions that could be effectively used for each material. The questionnaire responses regarding the use of teaching materials also were analyzed, resulting in the identification of 33 questionnaire statement that could be effectively used for this study. The pre-test and post-test questions relate to the anatomy and physiology of the respiratory, digestive, and urinary systems. The response questionnaire regarding the use of teaching materials includes student appraisal of teaching materials (satisfaction, perception, and appreciation), student interest, the usefulness of didactic workbooks, and the effectiveness of didactic workbooks in encouraging interaction between students. Only the experimental class was tested for its response to the use of didactic teaching materials. The pre-test and post-test questions used are as follows:

The respiratory system:

Q1 Write the names of the letters and verses in the Qur'an that explain the respiratory system and give an explanation!

Q2 Explain the main role of each part of the human respiratory system (e.g., trachea, bronchi, alveoli) in the process of gas exchange. Include *asma al husna* as seen in each role of each part of the respiratory system!

Q3 Explain the difference between the processes of inspiration and expiration in the human respiratory mechanism. Include the role of the diaphragm and intercostal muscles in both processes!

Q4 Describe the process of gas exchange that occurs in the alveoli of the human lungs. Explain how oxygen and carbon dioxide are transferred between the air in the alveoli and the capillary blood!

Q5 Explain the symptoms, causes, and treatment of one of the common respiratory diseases, such as pneumonia. Include ways of transmission and prevention efforts!

The digestive system:

Q1 Write the names of the letters and verses in the Qur'an that explain the digestive system and give an explanation!

Q2 Explain the main role of each part of the human digestive system. Include *asma al husna* as seen in each role of each part of the digestive system!

Q3 Describe the process of digestion of human food from the mouth to the small intestine, including the role of the enzymes involved in each stage!

Q4 Explain the process of fat digestion in the human small intestine!

Q5 Explain the symptoms, causes, and treatment of one common digestive disease!

The urinary system:

Q1 Write the names of the letters and verses in the Qur'an that explain the urinary system and give an explanation!

Q2 Explain the main role of each part of the human urinary system. Include *asma al husna* which is seen in each role of each part of the urinary system!

Q3 Describe in detail the process of urine formation from glomerular filtration to elimination as urine!

Q4 Explain the role of the kidneys in the regulation of blood pressure and electrolyte

	balance in the human body!
Q5	Explain the symptoms, causes, and treatment of one of the common diseases related to the urinary system!

Data Analysis

The t test was used to assess the difference between the increase in learning outcomes before and after treatment in the experimental group and control group. The learning outcomes data was evaluated for normality and homogeneity before the t test. The N-Gain test was used to determine if the didactic workbook was effective at improving learning outcomes. N-Gain states the gain normality test value and % *ideal score* represents % maximum score.

N-Gain is determined using the formula used by Abdurrahman et al. (2019) and Hanifah et al. (2023). N-Gain formula is:

$$N - Gain = \frac{\%\ posttest\ score - \%\ pretest\ score}{\%\ ideal\ score - \%\ pretest\ score} \quad (1)$$

Table 2

The effectiveness of N-Gain scoring

Percentage (%)	Criteria
<40	Ineffective
45-55	Less effective
56-75	Quite effective
>76	Effective

Note. Hake, 1999

Table 2 shows effectiveness of N-Gain score on 100 scale (with <40 indicating ineffective, 45-55 indicating less effective, 56-75 indicating quite effective and >76 indicating effective.

To compare whether there is a significant difference in the level of effectiveness of increasing student learning outcomes in the experimental and control group, an independent t-test is performed on the N-Gain score.

Students response to the didactic workbook was assessed using following formula, which was adapted from (Muliyardi, 2006).

$$Average\ student\ response = \frac{Total\ score\ of\ student\ respons}{Total\ number\ of\ criteria} \quad (2)$$

Table 3

Student response category

Average level of response	Category
>3.20	Very positive
2.40-3.20	Positive
1.61-2.39	Quite positive
0.80-1.60	Negative
<0.80	Very negative

Findings

Learning Outcome and Effectiveness of Teaching Materials

Student learning outcomes in the experimental and control groups before and after learning in human anatomy and physiology courses can be seen in Table 4. In Table 4, it is known that student learning outcomes in human anatomy and physiology courses show significant improvements from before to after learning in both groups, both experimental and control, for all physiological systems studied (respiration, digestion and urination). The experimental group showed greater improvements in learning outcomes compared to the control group. This is indicated by the significant difference ($p<0.05$) in the average scores before and after learning between the two groups. It can be concluded that the learning method applied to the experimental group provided better learning outcomes compared to the control group in human anatomy and physiology courses.

Table 4

Student learning outcomes in the experimental and control groups before and after learning in human anatomy and physiology courses

Course	Experiment Group		Control Groups		Sig.
	Before	After	Before	After	
Respiratory system	62.38 ± 8.63	79.33 ± 3.03	57.38 ± 11.56	67.84 ± 7.25	0.00
Digestive System	60.89 ± 9.92	79.33 ± 2.49	52.46 ± 9.39	64.69 ± 7.79	0.00
Urinary System	63.44 ± 10.14	79.94 ± 4.03	59.23 ± 8.25	68.92 ± 5.59	0.00
Mean ± SD	62.24 ± 9.56	79.53 ± 3.19	56.36 ± 9.73	67.15 ± 6.87	0.00

Note: The "Sig." column indicates that all differences between the experimental and control groups are statistically significant at level of 0.05.

To assess the effectiveness of using didactic workbooks in improving learning outcomes, the N-Gain formula is used. N-Gain is the difference between the scores before and after using the didactic workbook.

Table 5

The mean of N-Gain scores of experimental and control classes

Group	N-Gain Score (%)	Minimum N-Gain Score (%)	Maximum N-Gain Score (%)
Experiment	43.61	10.00	65.63
Control	22.88	-25.00	50.94

Note. N<40 is an ineffective category; 40-55 categories less effective; 56-75 categories are quite effective; >76 effective.

Table 5 indicates that the experimental group, which utilized the didactic workbook, achieved an N-Gain score of 43.61%, reflecting a higher effectiveness compared to the control group. Conversely, the control group attained an N-Gain score of 22.88%, indicating less effectiveness in comparison. Thus, it is known that there are differences in the effectiveness of increasing learning outcomes between the experimental class and the control class.

To compare whether there is a significant difference in the level of effectiveness of increasing student learning outcomes in the experimental group, an independent *t*-test is performed on the N-Gain score. Based on the independent *t*-test, it is known that Sig. 0.00<0.05. These data indicate that there is a significant difference ($p<0.05$) between learning outcomes of the experimental group compared to the control group. In other words, using didactic workbook significantly improves learning outcomes compared to resume and answer questions in the textbook. Didactic workbooks provide a more structured, logically sequenced learning framework, contain questions that require completion with a variety of activities and support all student learning styles compared to practice questions in textbooks, thereby helping students to understand the concepts of the material progressively, reducing cognitive load, facilitate better understanding and promote critical thinking. When students are given assignments or exercises that suit their learning style, they tend to be more motivated and engaged in the learning process. This is because the assignments better suit the individual's preferences and strengths, thereby increasing their confidence and interest in learning the material.

The learning outcomes using the task of working on a didactic workbook with a discussion were effective than the learning outcomes using the task of resuming and answering textbook practice questions with a discussion, also due to the existence of collaborative activities in solving problems in the workbook. Collaboration between students in problem solving will allow them to think critically and deeply about the subject matter, which can increase their understanding. Active participation in learning is shown to improve comprehension and retention of knowledge.

Students Response to Didactic Teaching Material

Students responses to didactic workbook were evaluated in terms of their acceptance of the materials, their interest in them after utilising them, their usefulness in enhancing learning outcomes, and their effectiveness in promoting student engagement. The results showed that students responded very positively (3.32 ± 0.43) to the workbooks used in learning (Table 6). So, it is well known that workbooks are used in very effective ways by students to learn.

Table 6

Students response to didactic workbook

No	Assessment Aspect	Mean ± SD	Category
A.	Acceptance of teaching materials		
	a. Satisfaction	3.37 ± 0.51	Very positive
	b. Awareness, perception	3.32 ± 0.52	Very positive
	c. Appreciation of teaching materials	3.35 ± 0.51	Very positive
	Average	3.35 ± 0.51	Very positive
B.	Learning interest after learning using teaching materials	3.4 ± 0.46	Very positive
C.	Advantages of teaching materials	3.22 ± 0.39	Very positive
D.	Effective in encouraging student interaction	3.32 ± 0.36	Very positive
	Average	3.32 ± 0.43	Very positive

Discussion

Learning Outcome and Effectiveness of Teaching Materials

This research focused on investigating learning outcomes and students' responses to a didactic workbook. A didactic workbook has questions that require completion with a variety of activities including contemplative practice, colouring, completing, contextualising in colour, crosswords, connecting, summarizing a picture, describing processes, sequencing a variety of illustrations and writing the results of contemplation activities. The research results show that didactic workbooks significantly improved student learning outcomes on this occasion (Table 4 and 5). Student responses to didactic teaching materials were very positive (Table 6).

This didactic workbook is able to improve student learning outcomes because it has a more organized, logically sequenced learning framework, contain questions that must be answered with a variety of activities, and support all student learning styles compared to practice questions in textbooks. These features help students comprehend the material more thoroughly, lessen cognitive load, facilitate better understanding, and encourage critical thinking (Mayer, 2002). Students are more likely to be motivated and involved in the learning process when they get tasks or exercises that are appropriate for their preferred learning style. This is because the assignments are more tailored to each person's interests and preferences, which boosts their confidence and piques their curiosity about the subject matter (Li et al., 2019; Lu et al., 2007). The learning outcomes using the task of working on a didactic workbook with a discussion were better than the learning outcomes using the task of resuming and answering textbook practice questions with a discussion, also due to the existence of collaborative activities in solving problems in the workbook. Collaboration between students in problem solving will allow them to think critically and deeply about the subject matter, which can increase their understanding (Johnson et al., 2014; Sweller, 2011). Active participation in learning is shown to improve comprehension and retention of knowledge (Prince, 2004).

The activities carried out in completing this workbook require students to be able to build their own knowledge, according to their learning style. Pashler et al., (2009) stated that students are more likely to participate actively in the learning process when the activities are tailored to their preferred learning styles. Their motivation and focus are maintained by this interaction, which improves their memory and comprehension of the subject matter. Colouring, summarising and writing activities provide good opportunities particularly for individuals with a kinaesthetic learning style because students with a kinaesthetic learning style do more physical activity. Students with a kinaesthetic learning style do more physical activity (Ariastuti & Wahyudin, 2022).

Interactive components like simulations and practical exercises are frequently included in didactic materials. By drawing students in and encouraging active engagement, these interactive elements enhance and stimulate the learning process (Sablić et al., 2015). Students are more motivated to engage with the information when it is connected to real-world situations, current events, or actual use. This helps students recognize the value and importance of what they are studying (Fernández & León, 2016; Delfita & Andrizal, 2016). Didactic materials often encourage active learning strategies such as problem-solving, critical thinking, and collaboration. These activities require students to be actively involved in constructing their own understanding of the material, which not only deepens learning but also increases motivation and engagement (Marneli et al., 2022). Students are more likely to feel encouraged and supported in their learning process when they come across engaging and stimulating resources. Good learning experiences promote self-efficacy and confidence, which boosts motivation and makes one more likely to persevere in the face of difficulties Akkuş and Doymuş, 2022). Besides that, contemplation activities that make the subject matter the object of contemplation make thinking deep and all-encompassing (Delfita et al., 2020; Song, & Muschert, 2014).

The availability of contemplative activities that make a subject an object of contemplation in the didactic workbook teaches students to focus their attention on a particular topic while also establishing a connection *asma al-husna* (the best names are based on the characteristics of God such as well meaning and kindly). According to Song and Muschert (2014), thinking becomes profound and all-encompassing when one is in a contemplative. In conjunction with contemplation, it can promote spirituality as well as self-awareness and compassion (Davidson et al., 2012; Zajonc, 2013; Delfita et al., 2020), boost attention, stimulates the work of the left and right brains (Jha, Krompinger, & Baime, 2007), and enhance metacognitive skills (Zeidan et al., 2010). According to critical thinking specialists (Kuhn, 2000; Nelson dan Rey, 2000), the practice of contemplation in the classroom promotes students to learn, question presumptions, and build metacognitive skills both individually and collaboratively. Therefore, didactic workbooks can improve student learning outcomes.

The use of didactic teaching materials to improve learning outcomes has been reported by Cardoso, Cristiano and Arent, (2009), dos Santos, FS, Guimarães, (2017) and Delfita *et al*. (2020). These three studies did not assess the efficiency of didactic teaching materials (didactic workbooks). In this study, we investigated the efficacy of utilizing didactic workbooks, and the results showed that using didactic workbooks increased learning outcomes when compared to courses that did not use them. The findings demonstrate that using didactic workbooks improves students' learning since they can serve as a source of knowledge in addition to the teacher's explanations. Cardona and Mendez's (2018) research supports the conclusions of this investigation. Their research has shown that using didactic teaching materials can increase student learning outcomes in English learning.

Students Response to Didactic Teaching Material

The student response to the workbook was very positive (3.32 ± 0.43 (Table 6). It motivats them to become involved in the activities prescribed. Their acceptance of this teaching material is because this teaching material has its own charm, is easy to understand, and stimulates them to learn. Sablić et al., (2015) stated that teaching materials would be well received by students if they were attractive and stimulated them to learn. When they find valuable and useful teaching materials, they will accept them and show readiness to introduce them in their regular teaching. Didactic materials meet all of the demands of students while taking into account their preferred learning methods (Khasanovna, 2021). They also help students reach their full learning potential and develop higher-order thinking skills (Fernández & León, 2016). By connecting the existing learning materials in teaching materials with *asma al-husna*, contemplation exercises encourage the development of universal values and make teaching materials more relevant. The existence of contemplation activities by linking the existing learning materials in teaching materials with *asma al-husna* also increases spirituality (Delfita dan Andrizal, 2016; Delfita et al., 2020), train concentration, develop argumentation skills and metacognitive abilities individually and interactively (Zajonc, 2013). Effiong dan Igiri, (2015) state that teaching materials that can meet and answer the needs of students will be liked and responded to very well by students. Delfita et al., (2020) state that didactic and contemplative-based teaching materials require student cooperation to complete assignments in teaching materials.

This research is in line with that of Cardona and Mendez, (2018), who found that students responded very well to didactic teaching materials and improving their writing skills as a result. This research responded students very positively and improved their understanding of human anatomy and physiology especially on respiratory system material, digestive system and urinary system. However, student responses to the use of didactic workbooks that have a variety of activities to complete and cater to all students learning styles in the study of human anatomy and physiology, have recently been the subject of reports on student responses.

Conclusion and Implications

It can be concluded from the findings and discussion above that the didactic workbook was effective in improving learning outcomes and very positive received by students. Teachers can use didactic workbook to facilitate students for active learning because the use of workbooks will lead them to self-study. They can also use didactic workbook as supplementary material whose contents can be discussed in class with them.

Research Limitations

Although the results of this study show that didactic workbooks can improve learning outcomes and that students respond positively to their use, several limitations must be acknowledged. First, the sample size for the study was very limited, namely only 31 students in Biology Education, which may not represent the larger student population or different student groups. Second, research is limited to three teaching materials, namely the anatomy and physiology of the respiratory system, digestive system, and urinary system. Third, researchers had little control over whether there were distractions from the environment around students, such as sounds in the surrounding environment, which could reduce focus and discipline in discussions, because these studies conducted online using Zoom meetings. Finally, monitoring engagement and understanding the material are difficult. It can be difficult to assess students' engagement and comprehension in online discussions. Online, participants may struggle to accurately demonstrate their understanding or engagement. Because of these limitations, more research is needed to confirm the use of face-to-face didactic workbooks in the classroom.

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Conflicts of Interest

No conflict of interest.

Ethical Statement

When this research was conducted, UIN Mahmud Yunus Batusangkar did not have specific protocols for this type of study. Nonetheless, the participants were informed that their data would be used solely for research purposes and that they would be unable to be identified in any publications resulting from the study.

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Research trends of science process skills in Indonesian science education journals

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ABSTRACT
Science process skills (SPS) are considered essential for scientific and technological eras nowadays. This study aims to provide information on how SPS in Indonesia have been researched from 2016 to 2022, including the number of studies conducted, research designs used, frequently addressed science topics, interventions, assessment instruments used, and data analysis techniques applied. We applied content analysis across numerous science education journals authored in Indonesia over 7 years. The analysed articles were filtered from 14 Indonesian science education journals selected from the SINTA database with SINTA 1-6 index ratings. Articles were searched using keywords such as "Science Process Skills and Science Education" and the selection resulted in the review of 86 articles. This up-to-date research has revealed a fluctuation in the number of articles mainly focused on SPS from year to year. Among those articles, quantitative research was the researchers' most popular method for examining SPS. 8th grade Junior High School (JHS) and 10th grade Senior High School (SHS) pupils were frequently chosen as study participants. The most frequently selected topic for the study of SPS were physics (38%), biology (33%), chemistry (9%), and unidentified topics (20%). Inquiry-based learning was the most common research focus, with test sheets and t-tests being the most frequently utilised for analysing data. This SPS review research is important to provide results to identify future areas of research and promote the development of SPS in science education. Several suggestions for future studies on SPS have been made based on the study's outcomes.

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Introduction

Science is not only the domain of scientists, but also an essential skill for everyone in the context of massive information flows and rapid change (OECD, 2016b). Advancements in science and technology wield significant influence across various fields, including the specific domain of science education. Science education strongly emphasises the learning process as well as information and thinking (National Research Council, 2012). The abilities used when participating in science-based activities in the learning process are called science process skills (SPS). SPS are more valued in today's scientific and technological periods than in previous decades (Gultepe, 2016). Gagne (1965) defined SPS as advanced abilities that scientists utilise in their scientific work. Scientists employ SPS techniques to examine or investigate a problem, concern, query or phenomenon that came up through their research (Duruk et al., 2017). Athuman (2017) further elaborates that SPS enables learners to probe their environment and construct their own understanding during the learning process, effectively linking the theoretical aspect of learning to its practical application. As outlined by Mustafa et al. (2021), it becomes crucial for educators to integrate SPS into their pedagogical frameworks when planning teaching and learning strategies. SPS should be incorporated into instruction for science to be taught successfully (Tilakaratne & Ekanayake, 2017).

Rezba et al. (2007) classified SPS into two categories: basic SPS, which are observing, communicating, classification, measuring, inference and predicting, and integrated SPS, which are identifying variables, creating a table, graphing, identifying the relationship between variables, collecting and processing of data, analysing, forming a hypothesis, identifying variables operationally, designing and conducting an experiment. Basic SPS provide a basis for the integration of SPS into school science curricula. Piaget (1964) suggested that with complete mastery of the fundamental SPS, learners are better positioned to cultivate abstract reasoning within an integrated SPS. Regular problem-solving and high order thinking activities can help develop these abilities (Adlim et al., 2020). Scientists use SPS to design experiments, conduct investigations, analyse data, and draw conclusions. These skills are a set of abilities that help scientists understand the natural world and solve problems systematically.

SPS are fundamental to scientific inquiry and are a powerful approach to learning and teaching science. Recent research has effectively highlighted the essential role of SPS as the foundation of scientific activities and a critical component of problem-solving (Abungu et al., 2014; Gültekin & Altun, 2022; Gultepe, 2016). The SPS must be mastered to comprehend science in the future. These abilities are also useful for daily problem-solving (Beichumila et al., 2022; Darmaji et al., 2020; Özgelen, 2012). In a study published in the journal of research in science education, researchers found that pupils in 4th grade and student in secondary school with stronger SPS were better able to solve complex scientific problems (Abungu et al., 2014; Gültekin & Altun, 2022). The study found that students who had a deeper understanding of scientific inquiry, such as designing experiments and analysing data, were more successful at solving complex problems than those who merely memorised scientific facts in conventional studying methods (Athuman, 2017). SPS significantly impact learners' academic and personal development and increase their taking responsibility for their learning (Karamustafaoğlu, 2011; Mutlu, 2020). By developing these skills, they can become better problem-solvers, critical thinkers, and communicators (Ekici & Erdem, 2020). Learners' scientific process skills influence critical thinking in acquiring scientific knowledge (Ekici & Erdem, 2020; Pradana et al., 2020). Learners' process skills and critical thinking must be gauged and enhanced for science learning to be achieved (Darmaji et al., 2020).

Despite the importance of SPS, several studies have found that SPS in various nations' curricula were still lacking. Widdina et al., 2018 categorized the student's basic SPS Profile as sufficient, shedding light on underlying factors contributing to this assessment. Firstly, a shortage of science teachers proficient in imparting science process skills to students was noted. Secondly, a deficiency in science resources and tools hindered teachers from effectively enhancing students' process skills. Lastly, inadequate support and guidance for teachers in assessing and developing students' science process skills were highlighted. The instrument used to measure SPS was a test, which was then scored as a percentage and converted into criteria ranging from very low to very high. In line with those studies, Hartono et al. (2022) also reported that the SPS of pupils in South Sumatra Province are in the medium category. The SPS of pupils in Lampung and Jambi are categorized as low

(Sunyono, 2018; Tanti et al., 2020). This may be due to limited resources, inadequate teacher training, and a lack of emphasis on inquiry-based learning in the curriculum (Sukarno et al., 2013; Widdina et al., 2018).

While significant research has been conducted on SPS, focusing on their development and effective teaching methods, gaps remain in the comprehensive understanding of SPS research, especially in the Indonesian context. Although previous research such as Idris et al. (2022) has made advancements in SPS studies, a comprehensive overview, particularly focusing on trends and prevalence of SPS-related research in Indonesia, is still lacking. Therefore, significant knowledge gaps are discovered due to the insufficient exploration of key aspects such as various research designs, frequently assessed topics, interventions for enhancing pupils' SPS, evaluation instruments, and appropriate data analysis techniques. This current research aims to bridge these gaps and enhance the understanding of SPS in an Indonesian context by applying content analysis to various Indonesian science education journals between 2016 and 2022.

Specifically, this study is intended to answer the following questions: (1) What was the trend in the abundance of studies on SPS from 2016 to 2022? (2) How were various research designs implemented to examine SPS in Indonesia? (3) What were the most frequently utilised topics used to assess pupils' SPS? (4) What intervensions did the researchers use to help pupils enhance their SPS? (5) What instruments did the researchers use to assess SPS? (6) How did the researchers analyse SPS?.

This study applies a methodology based on content analysis to comprehensively examine the scope of research related to SPS in Indonesian science education journals between 2016 and 2022. This study's differences from earlier ones that focused on SPS can be seen in various areas. Firstly, our analysis focused on publications mainly focused on SPS published between 2016 and 2022 that the Science and Technology Index (SINTA) recognised. SINTA (http://sinta2.ristekdikti.go.id/) is a science and technology development measurement platform conceived and developed by Indonesia's Ministry of Research, Technology and Higher Education. Secondly, multiple parameters were employed as the basis for content analysis. By examining the trends and gaps in SPS, we aim to identify areas for future research and promote the development of SPS in science education.

The significance of this study lies in its aim to fill the gaps and knowledge vacuum regarding SPS in the Indonesian education system. The significance of this study can be seen in its potential to contribute to the understanding and improvement of science education in Indonesia. By identifying areas for future research and highlighting gaps in current knowledge, this study can guide policymakers, educators and researchers in enhancing the teaching and learning of SPS. Additionally, the findings of this study can inform the development of appropriate interventions and assessment tools to effectively cultivate students' SPS in science education.

Methods

Research Design

This current research followed the guidelines of a content analysis study. The purpose of content analysis is to organise and elicit meaning from the data collected and to draw realistic conclusions from it (Bengtsson, 2016). Through content analysis, valuable insights into the abundance of research, research designs, prevalent topics, interventions, assessment instruments, and data analysis techniques are gained. This study aims to enhance existing knowledge on SPS and guide future research and practices within the field of science education. The research methodology employed in this study shares similarities with the approach utilised by Susetyarini & Fauzi (2020). They conducted a study examining articles on critical thinking skills in Biology education journals in Indonesia from 2010 to 2017. They found an increasing focus on critical thinking skills in recent years, with quantitative research being the dominant approach. Tenth-grade high school pupils were commonly studied, with ecosystems as the main topic. Project-Based Learning was the primary instructional method, and tests and *t*-tests were frequently used for data analysis. Authors propose further qualitative research, initiatives for developing basic critical thinking skills, accurately reported reliability of research instruments, and selection of suitable tests and research designs. This work highlights trends in critical thinking skill studies in Indonesian Biology education.

Data Source

The entire text of the articles was taken from 14 reputable Indonesian Science Education journals registered with SINTA 1-6 index ratings in October 2022. SINTA (http://sinta2.ristekdikti.go.id/) is a science and technology development measurement platform conceived and developed by Indonesia's Ministry of Research, Technology, and Higher Education. The SINTA 1-6 index is a ranking system that measures the quality and prestige of academic journals, with the highest-ranked journals classified as SINTA 1 and the lowest-ranked journals classified as SINTA 6. The search for articles on the subject of "Science Process Skills and Science Education" yielded a total of 86 articles. These articles were published online between 2016 and October 2022. The selection process involved examining each article to ensure its relevance to the topic. Out of the hundreds of articles gathered, 86 articles were found to specifically address Science Process Skills and Science Education.

Research Instrument

The content analysis methodology utilised in this study is based on the work of Philipp Mayring, which emphasises the importance of tailored approaches and maintaining consistency throughout the analysis process. By employing a content analysis approach derived from Mayring's theory, this study ensures a systematic and rigorous analysis (Mayring, 2015). The instrument employed for this study was a content analysis that included relevant features being observed, which are presented in Table 1. In selecting the primary aspects for content analysis, the study intentionally prioritised elements that would provide a comprehensive overview of the research landscape. These aspects were (1) the number of publications each year; (2) types of research; (3) the research subjects; (4) science topics employed for the studies; (5) interventions; (6) data collection instruments; and (7) methods for analysing data. The rationale behind the inclusion and exclusion of specific categories was twofold. Categories for aspects (1), (4), and (5) were not initially chosen because there were no prior studies to which they could have been compared to figure out what should be contained in the categories and because there was a chance that overgeneralised categories might emerge after performing content analysis on some articles. Before gathering data, categories (2), (3), (6), and (7) were also established. Aspect (2) was further broken down into two sub-aspects, including (2a) generic research types and (2b) type of quantitative research.

Table 1 presents the categories taken from Susetyarini & Fauzi (2020) and adjusted by the author. The author's adjustment of several categories underscores Mayring's call for content analysis to be adaptive and specifically constructed for the issue under examination. The selection of the seven primary aspects for analysis—publication frequency, research type variety, subject diversity, most selected topics, interventions, data collection tools, and analysis methods—mirrors Mayring's advice on systematically capturing the core elements that can thoroughly reflect the research landscape. This approach ensures that the content analysis does not become a generalised procedure but is instead able to highlight particularities and patterns within the data set (Mayring, 2015).

Data Analysis

Each article included in this study was categorised based on specific characteristics that matched the set criteria for each category. This categorisation was informed by the data articulated by the authors in the methodology and abstract sections of their respective articles. To efficiently visualise and present these categorisations and data, tables and bar charts were employed. This combination of comprehensive analysis and graphical representation allows for a clear and detailed understanding of the distribution and trends found within the examined articles. In this study, our approach to data categorisation is inherently based on the research question. This is congruent with the principles laid out by Hardwood & Garry, (2003), who advocate that data categorisation in content analysis should be systematically and primarily tied to the research question.

Table 1

Aspects and categories studied for content analysis in this research

Aspects	Categories	
Type of research (2a)	A.1-Development Method A.2-CAR A.3-Quantitative Research	A.4-Qualitative Research A.5-Mixed Method
Type of quantitative research (2b)	B.1-Observation Studies (OR) B.2-Correlational Research (CR) B.3-Survey Research (SR) B.4-Pre-Experimental Design (PED) B.5-True Experimental Design (TED)	B.6-Quasi Experimental Design (QED) B.7-Descriptive (DR) B.8-Comparative-Assosiative (CA) B.9-Ex Post Facto Design (EPFD)
Research Subject	C.1-Elementary Pupils C.2-VII Grade JHS Pupils C.3-VIII Grade JHS Pupils C.4-IX Grade JHS Pupils C.5-X Grade SHS Pupils C.6-XI Grade SHS Pupils C.7-XII Grade SHS Pupils	C.8-Undergraduate Students C.9-Postgraduate Students C.10-JHS Teacher C.11-SHS Teacher C.12-Lecturer C.13-Article C.14-Item Test of SPS
Data Collection Instrument	D.1-Questionnaire Sheet D.2-Observation Sheet D.3-Test Sheet	D.4-Interview Sheet D.5-Others
Data Analysis Methods	E.1-Mean E.2-Percentage E.3-N-Gain E.4- t-Test E.5-ANOVA E.6-ANCOVA	E.7- MANOVA E.8- Correlation E.9-Regression E.10-Qualitative Analysis E.11-Unidentified

Note. CAR= class action research; JHS= junior high school, SHS= senior high school; ANOVA= analysis of Variance; ANCOVA= analysis of covariance; MANOVA= multivariate analysis of variance.

Findings and Discussion

Abundance of Studies on SPS

The study results are presented in a chart in this section. Based on Table 2, the research on SPS in Indonesia has been ongoing for some time and is not a new area of interest for researchers in the country. The number of publications did not change in any pattern from year to year.

Table 2

The abundance of studies that focused on SPS in Indonesia in 7 years

Year of Publication	Total
2016	11
2017	14
2018	14
2019	10
2020	13
2021	16
2022	8

However, as seen in Table 2, the number of publications 2021 has increased higher than in previous years. The fluctuation in the number of publications echoes the varying levels of researchers' interest in investigating students' SPS over the years. However, the increase seen in 2021 was not mirrored in 2022. As of October 2022, the publication count receded to 8. Despite what seems to be a decline, the data for the full year of 2022 is not yet complete, suggesting that this data would likely change.

A noticeable spike in the number of SPS articles is observed in 2021. This upsurge hints at a novel trend within educational and pedagogical research. The potential surge in research focus on SPS in 2021 might be attributed to several factors, such as trends and interests, policy changes, and societal needs and global challenges such as the COVID-19 pandemic. The curriculum policy in Indonesia initiated a pivotal adaptation from the Curriculum 2013 to a limited implementation of the Merdeka Belajar (Emancipated Learning), starting in 2021 (Ministry of Education and Culture of Indonesia, 2021). This transition increased flexibility and responsibility for schools (school leaders and teachers) to ensure instruction addresses pupil needs and interests (Randall et al., 2022). Due to its adaptability and learner-centred approach, the Merdeka Belajar curriculum has a great deal of potential to improve pupils' SPS. The rise in SPS research in 2021 amidst the COVID-19 pandemic signifies an accelerated academic focus on students' SPS in independent and online learning scenarios (Dwikoranto et al., 2021; Rusmini et al., 2021). In essence, the increased emphasis on SPS research in 2021 is likely a result of a combination of these interconnected factors.

Susetyarini & Fauzi, (2020) emphasize that researchers' awareness of prevalent situations around them often serves as the inspiration for their studies. Researcher interest plays a crucial role in the volume of published articles within a particular domain. A surge in published works may occur if the field of scientific process skills garners significant attraction or if potential for vital discoveries or applications are perceived. SPS research in Indonesia's education system can have a significant impact. It improves educational practice by providing valuable insights to teachers for developing effective strategies. It also serves as a foundation for informed decision-making, influencing policy and governance. Additionally, it broadens educators' perspectives and encourages the adoption of innovative teaching approaches, leading to overall improvement in the field (Coburn & Penuel, 2016).

Various Research Designs in Investigating SPS in Indonesia

The focus of a study is determined by the designs and types of studies being conducted. According to Table 3, quantitative research was researchers' most popular approach to examining SPS. Quantitative research is favoured due to its ability to measure and analyse data objectively (Bryman, 2016).

Table 3

The distribution of research type that focused on SPS

Types of Research	Frequency
Quantitative	53
Development Method	24
Qualitative	4
Mix Method	4
CAR	1

This method allows researchers to discover patterns and relationships in large data sets, aiding inferences about SPS. The prevalence of quantitative studies aligns with claims that researchers frequently choose them over qualitative designs in educational research. This is supported by research carried out by Tadesse et al. (2022) which revealed that the commonly utilised research design and methodology was quantitative by quasi-experiment. Bryman (2016) stated that quantitative research methods are often preferred in education due to their ability to produce generalisable findings and to control for extraneous variables. As a result, the lack of qualitative and mixed method research has provided new researchers with an excellent opportunity to employ qualitative design and concentrate their studies on SPS.

The second most popular research design for evaluating SPS was the development method. This is consistent with other earlier studies that found development method to be the most popular research type (Fauzi & Pradipta, 2018). The findings suggest that quantitative research, supplemented by development method and mixed methods research, constitutes the mainstay methodologies employed in SPS investigations. Conversely, methodologies such as qualitative, mixed method, and class action research (CAR) are less typically written up and published in this field. Broadly, these underused research methods offer fruitful lines of inquiry for future researchers who are aiming to expand the scope and impact of SPS research.

According to Table 4, a quasi-experimental design was the most common experimental research concerning SPS. Several earlier studies have discovered that quasi-experimental designs were applied than experimental designs (Baydas et al., 2015); Tadesse et al., 2022). The popularity of quasi-experimental designs can be attributed to their ability to overcome practical limitations that may arise in research settings. One of these limitations is the challenge of random assignment and control in certain contexts. In real-world environments, it may be ethically difficult or practically unfeasible to randomly assign participants to specific treatments or interventions. This is particularly true in educational research, where considerations of ethics and the potential impact on participants are paramount (Creswell & Creswell, 2017; Lodico et al., 2006; White & Sabarwal, 2014). The daily operations and goals of schools further complicate randomisation, leading to ethical dilemmas, as some students may be denied beneficial interventions or exposed to unproven ones (Gopalan et al., 2020; Petosa & Smith, 2019). Quasi-experimental designs navigate these issues by using existing or self-selected groups, avoiding ethical issues around randomisation and often proving more cost-effective despite concerns such as autocorrelation and hidden confounds which can compromise result validity and causality claims (Kontopantelis et al., 2015). The increased use of quasi-experimental designs can also be attributed to factors such as improved methodological training, easier access to data, and a growing emphasis on evidence-based policy evaluations in education (Gopalan et al., 2020). However, researchers must be cautious in interpreting the results of quasi-experimental studies and consider alternative designs to provide a comprehensive understanding of SPS (Creswell & Creswell, 2017; Lodico et al., 2006). Additional explanations may come to light via further investigation, and as a result, the underlying causes may aid future researchers in choosing their approach with more knowledge.

Table 4

The distribution of quantitative research that focused on SPS

Types of Quantitative Research	Frequency
Quasi Experimental Design	34
Pre-Experimental Design	9
Descriptive	8
Comparative Research	1
Observation Studies	1
Correlational Research	0
Ex Post Facto Design	0
Survey Research	0
True Experimental Design	0

On the other hand, the scarcity or absence of various research designs such as Comparative Research (CR), Survey Research (SR), True Experimental Designs (TED), Ex Post Facto Designs (EPFD), and instances pertaining to Observational Research (OR) and Correlation Analysis (CA) may stem from multiple factors. While there are no specific sources that address this directly, some potential reasons are suggested below. The choice of these designs is significantly influenced by the practicality of the study and the nature of the research topic (Cohen et al., 2007). For instance, in certain cases, TED are considered the 'gold standard' for establishing cause-effect relationships. However, due to practical or ethical constraints, conducting a true randomised controlled trial might be challenging (Creswell & Creswell, 2018; White & Sabarwal, 2014). Classroom studies can be complex due to the need for direct intervention, making some research methods impractical for educational research. Surveys require large, diverse samples and are costly and time-consuming, with the added difficulty of eliciting genuine responses (Fraenkel et al., 2012; Lodico et al., 2010). CR also face the hurdle of diverse educational systems across cultures and regions (Bray & Thomas, 1995). EPFD struggles with the issue of independent variable control which could introduce confounding factors, affecting result validity. OR, while useful, faces difficulty in establishing causal relationships due to non-manipulatable variables and the risk of observer bias (Grimes & Schulz, 2002). CA can reveal relationships between variables but does not establish causality, which may result in incorrectly assuming causation from correlation. These restrictions encourage researchers to seek alternative methods better suited to their specific objectives and contexts.

The research suggests that various instructional designs have been used to empower pupils' and students' SPS, but with quasi-experimental designs prevailing. These designs allowed researchers to compare various instructional approaches and determine their effectiveness in improving pupils' and students' SPS. The researchers require study participants to provide evidence for their hypotheses. As depicted in Table 5, pupils from eighth grade of junior high school and tenth grade of senior high school were predominantly chosen as participants for the study, followed by higher education students. The reason might be related to the significance of the early adolescent period in academic and psychosocial development. The importance of this stage is supported by prominent theories, such as Jean Piaget's Theory of Cognitive Development, and influential assessments, such as the Programme for International Student Assessment (PISA).

Table 5

The distribution of research subjects that focused on SPS

Subject of Research	Frequency
VIII Grade JHS Pupils	19
X Grade SHS Pupils	19
VII Grade JHS Pupils	15
XI Grade SHS Pupils	11
Undergraduate Students	8
Elementary Pupils	3
IX Grade JHS Pupils	3
XII Grade SHS Pupils	3
Article	3
JHS Teachers	1
Item Test	1

According to Piaget, individuals at the age of 12 (typically corresponding to the eighth grade) enter the formal operational stage, marked by the ability to think abstractly, reason hypothetically, and consider multiple perspectives. Similarly, individuals around the age of 15 or 16 (corresponding to the tenth grade) are in the later stages of the formal operational period, demonstrating advanced cognitive abilities (Piaget, 1964). In traditional views, particularly from Piaget's perspective, scientific thinking is seen as a competency that develops during adolescence, once children reach the stage of formal operational development. PISA further underscores the importance of this age group, focusing on 15-year-olds presumed to have the necessary cognitive and social skills for complex tasks (OECD, 2017). This view has encouraged interest in investigating scientific inquiry in a similar demographic (OECD, 2016a; She et al., 2018). This consistent attention paid to secondary pupils in SPS research is evidenced by the findings in Sarıoğlu (2023) study of eighth graders. Likewise, research conducted in African countries found that high school pupils were reported to be the most researched subjects regarding SPS (Tadesse et al., 2022). The focus on this age range also underscores the possibility of a trend influenced by the rigorous cognitive demands of international assessments such as PISA.

Table 5 shows that research subjects within SPS studies have the fewest number of studies focusing on junior high school teachers compared to primary school pupils and undergraduate students. Although the authors may not have discerned explicit reasoning behind the research participant selection, this disparity could be attributed to the current research priorities on pupils and students over educators and the student-centred approach stipulated by Indonesia's recent educational reforms of Curriculum 2013 and Merdeka Belajar (Randall et al., 2022). As many nations move towards industrialization, honing pupils' SPS through student-centred approaches such as problem-based learning is one of the keys to preparing them for today's world Kasuga et al., (2022).

Science Topic Selected when Conducting Studies in SPS

Based on Table 6, the distribution of science topic selections in studies focused on SPS reveals that physics and biology were the most commonly chosen fields. Physics accounted for 38% of the selected research topics, while biology comprised 33% of the total. Researchers often select physics as a research topic for studying SPS due to its foundational role in scientific inquiry. Physics offers a wide range of topics that allow researchers to develop essential skills such as observation, measurement, data analysis, and experimentation. Research has shown that the study of physics is closely linked to the development of SPS, such as observing, inferring, predicting, and communicating, making it a natural choice for such investigations (Wiwin & Kustijono, 2018).

Table 6

The most selected science topics in SPS studies

Dicipline	Topic	Frequency	%
Biology	Human Organ Systems (8); Environmental issues (7); Ecosystems (5); Biotechnology (2); Biodiversity and Natural Resources (2); Vertebrates (1); Cell metabolism (1); Photosynthesis (1); Skin health issues (1)	28	33
Physics	Temperature, heat, and heat transfer (6); Electricity and electromagnetism (6); Light (4); Fluids (3); Kinematics (3); Work and energy (3); Rotational Dynamics and Rigid Body Equilibrium (2); Biophysics (1); Optical tools (1); Sound waves (1); Measurement (1); Pressure of substances and their applications (1); Elasticity and Hooke's law (1)	33	38
Chemistry	Solution and Solvent (3); Hydrolysis (2); Chemicals around us (2); Separation of mixtures (1)	8	9
Unidentifiable	Unspecified Topic (17)	17	20

In comparison to Biology and Physics, Chemistry represents a smaller proportion of the topics chosen for studies in SPS. The reasons for this might involve various factors. The limited number of studies on chemistry topics in SPS research may be due to the perception that chemistry education is more focused on content knowledge than on the development of process skills. Additionally, research has shown that chemistry teachers may have a limited understanding of SPS and their assessment in chemistry learning (Hikmah et al., 2018). Therefore, there is a need for more research on SPS in chemistry education to promote the development of these skills among pupils.

However, a significant portion of the data, accounting for 20%, falls into an unidentified category with unspecified topics. This is mainly due to four studies involving content analysis, which does not require a specific topic, and some studies that did not clearly specify their research focus. Additionally, there were some studies that failed to adequately articulate their research focus. In order to remedy this issue, it is crucial for future researchers to provide more detailed explanations about the specific research topic they are investigating. Clear and explicit descriptions of study goals will greatly assist in properly categorizing research areas within the domain of SPS. By doing so, we can enhance the overall clarity and effectiveness of research efforts in this field.

Interventions Employed when Conducting Studies in SPS

The purpose of giving interventions is to evaluate the researchers' hypothesis or determine the importance of a certain condition compared to any studied parameter. Based on Table 7, inquiry-based learning was the most selected interventions when conducting studies on SPS.

Table 7

The most used intervention types in SPS studies

Interventions	Articles
Inquiry-Based Learning	12
Project-Based Learning	9
Practicum	8
Scientific Approach	5
Problem-Based Learning	4
STEM Approach	4
Discovery Learning	4
Models Science, Engineering, Technology, and Society (SETS)	4
Oudoor Learning	4
Contextual Learning	3
Cooperative Learning	2
Science Process Skills-based Learning	2
Problem Solving	1
Quantum Teaching	1
C3PDR teaching model	1
Predict-Observe-Explain Learning Model	1
Learning Cycle 5E With Mind Mapping	1
Model Numbered Head Together (NHT)	1
ICARE Learning Model (Introduction-Connect-Apply-Reflect-Exten)	1
Application of Multipurpose Optical Kit (AP-KOS)	1
Application of Integrated Worksheets with Terrarium Media	1
Conceptual Attainment Worksheet	1
Unidentified	17

Twelve articles used inquiry-based learning, likely due to its student-centred approach fostering active participation in scientific processes, crucial for building SPS. Implementing inquiry-based learning in physics can elevate pupil engagement, independence, and attentiveness while improving their scientific ability to discover an idea via experimentation (Maison et al., 2021). Çepni et al., (2017) underscores the enduring significance and frequent research interest in the inquiry approach within physics education. This approach has proven effective in developing process skills among pre-service science teachers (Şen & Vekli, 2016; Wola et al., 2023; Yakar & Baykara, 2014), and shows promising improvements in pre-service teachers and pupils SPS scores (Çetinkaya & Özyürek, 2019; Ekici & Erdem, 2020; Hardianti & Kuswanto, 2017; Prayitno et al., 2017).

In education, inquiry-based activities are beneficial for developing pre-service science teachers' and pupils' SPS and conceptual understanding (Idris et al., 2022; Mutlu, 2020). Experienced teachers often find themselves more effective at utilising this approach than less experienced ones (Shahat et al. , 2022). A meta-analysis of 72 studies found that guided inquiry, offering variable assistance to pupils and students, has proven to enhance domain-specific knowledge and SPS (Lazonder & Harmsen, 2016). However, this approach might not be suitable for beginners due to the required self-discipline and potential for misconceptions if not properly structured (Kirschner et al., 2006).

Project-based learning was the second most popular research interventions in SPS. The learning process involves pupils designing activities, and giving direct experience in project-based learning can help improve their SPS. This is supported by the research by Nasir et al. (2019), which said that project-based learning instruction effectively improves pupils' SPS. Similarly, a study by Nurulwati et al. (2021) confirmed the effectiveness of project-based learning in enhancing pupils' SPS. This approach enhances scientific reasoning and observational skills through practical activities. Project-based learning combined with STEM supports pupils' active learning, improves their group dynamics when solving scientific problems, and prepares them for doing scientific research in the actual world (Baran et al., 2021; Kurniahtunnisa et al., 2023). However, it may present assessment challenges, time constraints, and difficulties achieving desired SPS outcomes (Sumarni, 2015).

Out of the total articles analysed, 17 articles that could not be identified as to which interventions they applied. Among these 17 articles, two of them were focused on content analysis, which does not involve a specific intervention. The remaining articles utilised descriptive analyses, which also do not require specific interventions for their research purposes.

Instruments Employed by Researchers to Assess SPS

Research projects must be based on data gathered from relevant sources using the proper techniques to have a significant impact. Following the learning process, SPS may be assessed in various ways. As shown in Table 8, the test sheet has been the most frequently used tool to gather information about SPS. This result is consistent with research done by Fugarasti et al. (2019), who found that the most used instrument to assess SPS was the Science Process Skills Test (SPST), a multiple choice test.

Table 8

The distribution of data collection instruments when conducting studies that focused on SPS

Data Collection Instruments	Frequency
Test Sheet	52
Observation Sheet	45
Questionnaire Sheet	12
Interview Sheet	4
Others	5

Test items can be created to assess specific SPS such as observing, classifying, inferring, predicting, measuring, communicating, hypothesising, experimenting, interpreting data, and formulating models. Tadesse et al. (2022) also supported the importance of the SPST in their research. They emphasised the extensive coverage of the test, arguing that its multifaceted test items allowed for evaluating a broader range of skills. The SPST assessed fundamental SPS and explored more advanced abilities, such as formulating hypotheses, designing experiments, analysing gathered data, and formulating models. This comprehensive instrument facilitated assessing pupils' capabilities in applying these skills across varied situations, effectively determining their competence in SPS.

Tests evaluating one or more SPS can effectively measure people's abilities if used on a large sample (Shahali et al., 2017). Large-scale testing helps understand the participants' skills, assess skill distribution changes, and recognize their abilities' scope and extent. The drawback is that it is not possible to observe pupils' and students' SPS directly. The results of these tests can be statistically evaluated to ascertain the distribution of scores, the range of abilities, and any patterns or links between SPS and other factors. Test-based data collection is more objective than questionnaire- and observation-based methods.

Science process skills may be measured using both testing and non-testing methods. As a non-test method, the observation sheet offers the advantage of closely observing the pupil's and student's process skills. However, a drawback is the challenge of applying this test to a large sample. Following the learning process, SPS can be assessed through various approaches. A feasible assessment approach for assessing SPS was observation or performance and written questions based on the indicators of SPS (Kurniawati, 2021). A balance in the evaluation procedures educators and evaluators use is essential, considering these possible difficulties. They should thoughtfully mix standard examinations with a variety of other evaluation techniques, such as observations, questionnaires, and interviews. Observation sheets and questionnaire sheets are prominent techniques for assessing SPS. According to this content analysis, observation sheets were used in 45 articles, and questionnaires were used in 12 articles. Researchers often prefer to use observation sheets rather than questionnaires and interview sheets when assessing SPS for several reasons. This is because observation allows for a direct and efficient assessment of students' hands-on experimentation, capturing cognitive functions, procedural skills, teamwork, and communication (Butler et al., 2005). It avoids the potential inaccuracies of interview sheets, which are contingent upon students' ability to recall and articulate their thought processes, something that can lead to underreporting of abilities due to issues like recollection challenges or discrepant verbal skills (Taherdoost, 2021; Yin, 2009). Additionally, observations can be more practical for the simultaneous evaluation of multiple students in a classroom setting, streamlining the data collection process and reducing time spent on interviewing and analysis (Taherdoost, 2021). Despite these advantages, it is important to keep in mind that observations are not without their own limitations, such as observer bias, where the observer's subjectivity can skew the results (Campbell & Stanley, 1963; Cohen et al., 2007). This issue arises when the observer's background, expectations, or personal perceptions influence the observation, resulting in inaccurate findings (Lodico et al., 2010). To ensure a comprehensive assessment, adopting a mixed-methods approach tailored to the objectives of the evaluation could be a more efficient solution in specific situations.

In our analysis, "other" assessment techniques encompass 5 additional instruments, including 4 studies using content analysis methods such as The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and literature review criteria (document analysis). Meanwhile, one study did not explicitly mention the instrument used within the article. Qualitative researchers employ an assortment of tools in their investigations, but they often prefer to use observations method, conduct interviews, and conduct document analysis (e.g., data from school or public records, documents, or pictures) (Lodico et al., 2010).

Data Analysis Methods Used in Evaluating SPS

The validity of the research would be determined by how accurately the method for data analysis was chosen. As illustrated in Table 4, among studies concerning SPS, quasi-experimental designs were the most frequently adopted experimental approach, being featured in 34 articles. However, it is noteworthy that, as seen in Table 9, only one researcher chose to employ ANCOVA (Analysis of Covariance) for data analysis. This reveals a possibly missed opportunity, as ANCOVA is particularly adept at controlling for covariates in quasi-experiments, which in turn enhances the precision of the results. Before attempting any study, researchers should select the test that best suits their hypothesis and research plan before beginning any investigation.

Table 9

The distribution of data analysis method when conducting studies that mainly focused on SPS

Data Analysis Method	Frequency
T-Test	25
N-Gain	23
Percentage	15
MANOVA	10
MEAN	10
Correlation	8
ANOVA	5
Qualitative Analysis	3
Regression	3
ANCOVA	1
Unidentified	2

Quasi-experimental designs are frequently adopted in studies, and they can be paired with ANCOVA for data analysis. Quasi-experiments lack full randomisation, and ANCOVA helps control for the effect of additional variables, making it suitable for such designs. ANCOVA is used to examine differences in a continuous variable while controlling for the effect of other variables, and it can be applied to both between-subjects and within-subjects designs. Therefore, the choice of ANCOVA as an analytical technique is important in ensuring the validity and reliability of research findings, especially when quasi-experimental designs are employed (Tabachnick & Fidell, 2019). This significant connection underscores the necessity of choosing suitable analytical methods that align with the experimental design. This ensures the validity and reliability of research findings. Using ANCOVA with quasi-experimental designs allows effective control over extraneous variables for accurate results. Hence, the selection of appropriate data analysis techniques is crucial for researchers.

This analysis suggests a significant gap in methodological choices within the field. To fill this gap, enhanced training and awareness of advanced statistical methods that fit particular research designs are needed. By incorporating advanced data analysis techniques into academic curriculums, running workshops and seminars, and placing an increased emphasis on statistical education during the initial research preparation stage, researchers can make informed methodological selections.

The most common method of data analysis, as shown in Table 9, was the *t*-test, and the second was N-gain. This discovery has made it clear that the researchers frequently utilized the t-test to contrast the performance of two groups or classes. Many researchers choose to use *t*-test and N-gain in their data analysis for several reasons. Firstly, The t-test and N-gain analysis are popular choices for researchers due to their simplicity, wide usage, and ability to provide valuable insights into the effectiveness of teaching methods (Knapp & Schafer, 2009). Secondly, the *t*-test approach is preferred when the focus is on quantifying the amount of improvement in either of the conditions, rather than specifically comparing the reasons for the differences in effects (Wright, 2006). The researchers discovered two trends when using the t-test as a hypothesis test. First, the researchers gathered post-test data from every class, which they verified using a t-test. Second, before computing N-gain from both data sets, the researchers utilized the pre-test and post-test data. The N-gain for both classes was then tested using a t-test. These kinds of tendencies may decrease the research's validity. This inaccurate use of data analysis methods mentioned earlier aligns with the results reported in a study conducted by (Fauzi & Pradipta, 2018).

The application of ANCOVA is highly recommended, especially when researchers seek to select a nonexperimental design in which they cannot select each pupil or student individually as their study subject (Lodico et al., 2010; Tabachnick & Fidell, 2019). ANCOVA has the potential to be more effective and reduce both the risk of erroneous results and other experiment-wise errors. It may also address questions regarding the reliability of a complicated statistical conclusion reached after several t-tests (Taherdoost, 2020). In this context, the researchers might utilise ANCOVA to adjust for any external factors that could influence the relationship between the independent and dependent variables. ANCOVA is a more suitable method in several cases as compared to a t-test for analyzing differences, and therefore, it should be the preferred method in those situations (Wright, 2006). ANCOVA can address some of the limitations of T-test and N-gain by controlling for other variables that might influence the outcome (Tabachnick & Fidell, 2019). In conclusion, ANCOVA is advised for use in quasi-experimental studies that include pre-and post-test data. For forthcoming research, it's crucial to have a thorough understanding of data analysis techniques and underscore the importance of their appropriate application in the study.

In addition to the t-test and ANCOVA techniques, researchers utilize other statistical techniques such as MANOVA, correlation analysis, mean, and percentages in various research contexts. These techniques provide valuable insights, are used to study and predict outcomes, summarize data, and find applicable uses in fields such as social sciences, psychology, economics, healthcare research, survey data analysis, epidemiology, and market research. MANOVA extends ANOVA for analyzing multiple dependent variables, correlation analysis determines the interdependence between continuous variables (Fraenkel et al., 2012; Tabachnick & Fidell, 2019). Mean summarizes the central tendency of a dataset, and percentages facilitate comparison across categories or groups (Manikandan, 2011).

Conclusion and Implications

This study examined publications highlighting SPS in science education in Indonesia between 2016 and 2022. A fluctuating trend was observed in the number of articles on SPS published each year. The analysed articles were filtered from 14 reputable Indonesian science education journals selected from the SINTA database with SINTA 1-6 index ratings. Articles were searched using titles and keywords such as "Science Process Skills and Science Education," and the selection resulted in the review of 86 articles. This up-to-date research has revealed a fluctuation in the number of articles mainly focused on SPS from year to year. Among those articles, quantitative research was the researchers' most popular method for examining SPS. Furthermore, 8th grade JHS and 10th grade SHS pupils were frequently chosen as study participants. The most frequently selected topic for the study of SPS were physics (40%), biology (34%), chemistry (10%), and unidentified topics (17%). Inquiry-based learning was the most widely utilized interventions, with test sheets and t-tests being the most frequently utilized for obtaining and analysing data techniques.

According to the research results, further research recommendations have been made. Firstly, it is necessary to increase the frequency of qualitative research to examine the enhancement of SPS. Secondly, the researchers must provide explicit information regarding the reliability and validity of their study instruments. Before attempting any study, researchers should select the test that best suits their hypothesis and research plan before beginning any investigation. By adopting these recommendations, researchers can help improve the overall quality and relevance of studies on SPS in science education. Based on this study, we hope it will facilitate researchers interested in SPS research in science education. It will enable them to find appropriate and diverse primary references and formulate variables that need to be studied for further research. Educational practitioners, including teachers, lecturers, and policymakers, can adapt the results of this SPS research to implement them in science teaching and uplift learning quality.

Declaration of Interests

The contributors of this investigation certify that this manuscript is neither previously published nor being currently evaluated for publication anywhere else. Furthermore, there are no conflicts of interest that we need to reveal.

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First-year undergraduate biology education students' critical thinking and self-regulation: Implementation of a metacognitive-based e-learning module

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ABSTRACT
This study examines the improvement of first-year students' critical thinking and self-regulation by implementing a metacognitive-based e-module. To address the challenges of learning in accordance with the demands of the higher education curriculum, metacognitive-based e-modules are required. Metacognitive strategies such as analogies, concept maps, mnemonics, and discrepant events integrated into e-modules encourage students to be more critical and independent when understanding concepts and solving problems. The study employed quasi-experimental with two groups, a study group (instructed metacognitive-based e-module) control group (conventional module). Eighty-three students as respondents were involved. The descriptive results indicate that cognitive strategies promote curiosity, facilitate understanding, and aid in long-term memory. Metacognitive-based e-modules could encourage awareness, learning activities, evaluation and interpersonal skills. There is a significant difference in students' ability to think critically and self-regulation. The metacognitive strategy using e-module was found to be stimulating, thought-provoking, and facilitating students to have critical thinking and self-regulation.

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Introduction

In the 21st century, the demand for individuals who possess the intellectual prowess to navigate complex challenges is growing. Driven by technological advancements, society's transformation has highlighted the urgent need for a new breed of skilled and adaptable human resources. This has spurred a call for a paradigm shift in educational institutions, compelling them to undergo significant reforms. It is imperative that we arm our students with the fundamental abilities and capabilities necessary to not just endure but prosper within this time of unprecedented transformation. The Partnerships for 21st Century Skills (P21CS) in 2008 identified a spectrum of skills that are indispensable to both teacher and learner alike. These skills, range from critical thinking and creativity to communication and collaboration to the ability to apply knowledge in solving problems.

The ability to think critically is paramount. A complementary skill that assumes equal significant is self-regulation where students are trained to manage their learning strategies. This multifaceted skill empowers student to not only navigate their learning journey but to effectively manage and adapt their learning strategies. Enhancing critical thinking skills in higher education requires an increase in self-awareness, self-efficacy and metacognitive regulation through problem-based learning and collaborative learning (Rivas et al., 2022; Sutama et al., 2022). According to Yan (2020), enhanced academic achievement is strongly predicted by self-regulation, which offers positive feedback. Improving critical thinking skills in higher education can be achieved through problem-based learning strategies, experiential learning, and puzzle-solving (Prapulla et al., 2022).

Nurturing critical thinking and self-regulation is not merely a pedagogical concern but a societal imperative for whom the role of education is in sculpting a generation of intellectually agile and resourceful individuals who can confidently navigate the complexities of the 21st century. In the realm of higher education, surveys indicate that first-year students tend to possess low critical thinking skills and self-regulation. The results of a survey of several modules used at the authors' institution revealed that the modules used in the Basic Biology course lacked exercises and assignments based on examples of contextual problems, as well as content that trained analysis and problem-solving skills. According to the needs analysis of 49 respondents, several indicators of critical thinking skills and self-directed learning remain low, particularly in the areas of making conclusions, organizing strategies, and being aware of one's thoughts. This suggests a need for focused interventions to enhance these skills. The availability of self-regulation resources, such as e-modules that incorporate metacognition, is expected to address the challenges of improving learning in higher education, particularly for first-year students. An array of studies conducted by Thomas (2011) highlight a challenge posed by the 1st year students exhibiting deficiencies in both critical thinking skills and self-regulation. Moreover, Thomas, (2011) affirms that the ability to think critically should be developed from the first year students enroll at university. This development is crucial for their academic success and for meeting the demands of prospective employers upon graduation.

However, there are few e-modules available for higher education biology courses in Indonesia. Most universities primarily develop modules focused on metacognition. This study aims to create a module to foster critical thinking and self-regulation in first-year students. In metacognitive theory, students must have a particular aptitude to control and manage what they learn. According to Iskandar (2014) the aptitude encompasses abilities including problem-solving, decision-making, and critical evaluation. In another study, Murtini et al., (2020) state that the a metacognitive approach to teaching and learning optimises students' participation and increases students' critical thinking. That notion is also supported by a study conducted by Ali et al. (2017) which affirms that the metacognitive approach aims to enhance one's awareness in the context of self-regulation encompassing designing, controlling what is known, what is needed to do it, and how to do it, especially in solving problems.

Based on the result of a needs analysis that was previously conducted by the authors, it is necessary to improve the quality of students' learning through the provision of self-regulation resources in the form of an e-module. This e-module was expected to stimulate critical thinking ability and self-regulation by developing metacognitive strategies in students such as mind mapping, mnemonics, discrepant events (unique facts that challenge understanding), analogy, concept maps, and writing summary. An e-module was chosen not only due to the demand for dynamic learning but also because of the numerous advantages it offers, including its interactive nature, the inclusion of images, audio and video, along with formative tests that allow for direct automation with online worksheets, its suitability for university students' problem-oriented learning, its flexibility, as it can be accessed both online and offline, and its allowing students to conduct individual or group investigations, analyses, and evaluations in problem-solving. Therefore, this research focused on methods for improving the critical thinking skills and self-regulation of first-year students through the implementation of a metacognitive-based e-module. Students' responses to learning using this metacognitive-based e-module were also an important part of the study.

This study applied the metacognitive-based e-learning module to basic science courses of a college located in Riau, Indonesia. Students majoring in biology education used the metacognitive-based e-learning module over 8 weeks.

Research objectives:

1. How does the implementation of a metacognitive-based e-module impact the critical thinking skills of first-year students?
2. How does the implementation of a metacognitive-based e-module impact the self-regulation skills of first-year students?
3. What are the effects of the metacognitive-based e-learning module on promoting first-year students' views on critical thinking and self-regulation?

Literature Review

The literature review in this study begins with the observation that current biology learning conditions are not fully optimized. Various studies indicate that traditional teaching methods in biology often fail to engage students effectively, leading to suboptimal learning outcomes. To address these issues, there is a growing body of research advocating for innovative approaches that integrate metacognitive strategies into teaching materials. Such integration has been shown to significantly enhance critical thinking skills and promote learning independence among students. This literature review explores the necessity and effectiveness of these metacognitive interventions, providing a foundation for the proposed innovations in biology education.

The scope of the conceptual framework for this study focuses on the development and implementation of a metacognitive-based e-module aimed at enhancing critical thinking and self-regulation among students. The metacognitive strategies embedded in the e-module will create an environment conducive to knowledge construction and self-directed learning. These strategies enable students to control and evaluate their learning processes effectively, thereby enhancing their ability to seek and assimilate new information (Dökmecioğlu et al., 2020).

To establish a foundation for this framework, it is essential to review the existing literature on metacognition in education. This review will cover the theoretical underpinnings of metacognitive strategies, their application in educational settings, and their impact on critical thinking and self-regulation. By understanding these aspects, the study aims to justify the integration of metacognitive strategies into the e-module and highlight their potential benefits in improving student outcomes.

Metacognitive-Based E-Module

It is assumed that the integration of the metacognitive approach into learning materials is likely to train thinking control and decision-making, which was supported by the results of this study. The findings disclosed a substantial rise in the post-test average scores of students using the metacognitive-based e-module compared to their counterparts who did not use it, affirming that these strategies enhance critical thinking and self-regulation. According to Kamus Besar Bahasa Indonesia (The official dictionary of the Indonesian Language), a module is a teaching and learning programme that can be studied by students with minimal instructions from the lecturers, and minimum delivery of contents, tools and equipment necessitated to measure students' achievement in learning. The researchers developed a modular digital format consisting of textual and visual content addressing metacognition which users could access either by connecting online or working offline on screens of electronic devices such as computers.

Learning activities using a metacognitive approach involve planning, observation, and results monitoring. Metacognitive activities transpire through four stages: formulating hypotheses, making enquiries, drawing conclusions, and solving problems. Metacognitive skills are beneficial for students in terms of awareness and responsibility towards their knowledge; thinking skills and problem-solving; cognitive regulation; understanding learning materials and regulating learning strategies, and as preparation for facing learning assessments (Setiawati & Corebima, 2018). The implementation of metacognitive strategies, particularly in the context of discrepant events, can significantly increase higher-order thinking skills. Discrepant events, which are unexpected or surprising occurrences that challenge students' preconceived notions, provide a unique opportunity for deeper cognitive engagement. By prompting students to re-evaluate their understanding and apply metacognitive strategies, these events effectively foster critical thinking and problem-solving skills (Annisa, 2020; Weinert & Kluwe, 1987). The analogy strategy is a conceptualization that is a part of higher-order thinking (Yuningsih & Susilo, 2018). Metacognition constitutes an indispensable aspect of the learning process when it comes to the acquisition of knowledge.

Studies associated with the relationship between metacognitive strategy and academic achievement Abdelrahman, 2020; Neena & Sneh, 2015; Pudiquet et al., 2019; Rum & Ismail, 2016 show a positive correlation between the use of metacognitive strategies and academic achievement in higher education. The correlation can vary depending on the field of study, location and training (Ahdhianto et al., 2020; Rosdiana et al., 2023).

Several strategies can be applied to stimulate metacognitive skills such as a mind map, a discrepant event, a mnemonic, an analogy, making an inference, making a summary, and others. Several strategies can be applied to stimulate metacognitive skills, such as mind mapping, using discrepant events, employing mnemonics, drawing analogies, making inferences, and summarizing. The e-module designed on a metacognitive basis integrates these strategies, including discrepant events, mnemonics, and analogies, into the learning materials for each sub-chapter (learning activity). The integration of discrepant events aims to captivate students' interest and motivation by encouraging them to search for data and solutions to unusual or unexpected occurrences, as well as to explain everyday phenomena that may require deeper understanding. The analogy concept is chosen to create images and metaphors to visualise difficult concepts. The integration of the mnemonic method intends to foster memory through coding principles of long-term memory in an engaging manner.

Critical Thinking

Metacognitive skill correlates with the development of critical thinking and is a key aspect of increasing students' cognitive ability (Warni et al., 2018; Son, 2020). Metacognitive learning activities train one's cognitive processes through experiences of organising, connecting information, critical thinking, and problem-solving (Oflaz, 2021). According to Akpur (2020) critical thinking theory is significantly associated with reasoning and problem-solving. Critical thinking is frequently understood as an intellectual activity that is closely related to reasoning and inference (Maimun, 2022). In addition, Rivas et al. (2022) state that critical thinking encompasses problem-solving and decision-making. Thus, critical thinking, as a multifaceted concept, shares strong ties with diverse cognitive operations.

Further research is expected to expand the implementation to cover at least eight topics or more. Additionally, future studies could be conducted in blended learning environments on a larger scale, involving a more diverse group of participants. This approach could provide a broader understanding of the effectiveness of metacognitive strategies across various subjects and learning contexts.

A study carried out by Elaldı & Semerci (2014) showed a significant correlation between all sub-dimensions of metacognitive beliefs and students' critical thinking scores. Cakici (2018), Gurcay & Ferah (2018), and Lusia & Aloysius (2018). all declare that there is a positive correlation between metacognitive and critical thinking skills. Metacognition is the best predictor for improving critical thinking skills. A person's critical thinking ability will increase in line with the metacognition process (Dökmecioğlu et al., 2020). Metacognition leads to higher-order thinking skills, involving active control of certain cognitive processes in learning (Chang et al., 2020; Kozikoğlu, 2019). These skills include the ability to reason, problem-solve, infer, and make decisions. The metacognitive strategies integrated into the e-module, such as discrepant events, analogy, and mnemonic techniques, have been shown to specifically enhance university students' critical thinking skills. These skills are essential for effective reasoning, problem-solving, inferring, and decision-making (Chang et al., 2020; Kozikoğlu, 2019).

Self-Regulation

Self-regulation can be described as one's ability to read a situation or the environment, and controlling and managing behavioural factors in a way that is appropriate to the situation at hand. Another way to describe self-regulation is as a person's social-cognitive process of self-control, which includes self-adjustment for behavioural change, environmental adaptation, and conceptual knowledge (Frazier et al., 2021). Self-regulation is also defined as a process that allows an individual to conduct their own pursuits over a period to achieve the desired goals and to change the situation the other way around, including regulating the mind and behaviour. Individuals control themselves by observing, considering, and then awarding, or punishing their behaviour (Porath & Bateman, 2006). This self-regulation system of observing, evaluating, and reacting to oneself is a widely observed aspect of human behaviour (Baumeister, 2018) defines self-regulation as self-control to sustain a desired standard. This understanding of self-regulation underpins its importance in achieving personal and professional goals.

University students who are capable of regulating themselves are likely to have greater academic success. They can study effectively by combining academic learning skills and self-control which can facilitate the learning process and motivation. Mccombs & Marzano (1990) explicate some indicators of self-regulation, namely recognising one's own thoughts, identifying and using information, being receptive to feedback, evaluating the effectiveness of actions, and making effective plans. The integration of metacognitive strategies in the e-module in this study includes features like the "Let's think" section, which guides students in using self-regulation strategies to answer questions and seek information. This approach enhances students' ability to regulate their learning process and improve their academic performance.

Methods

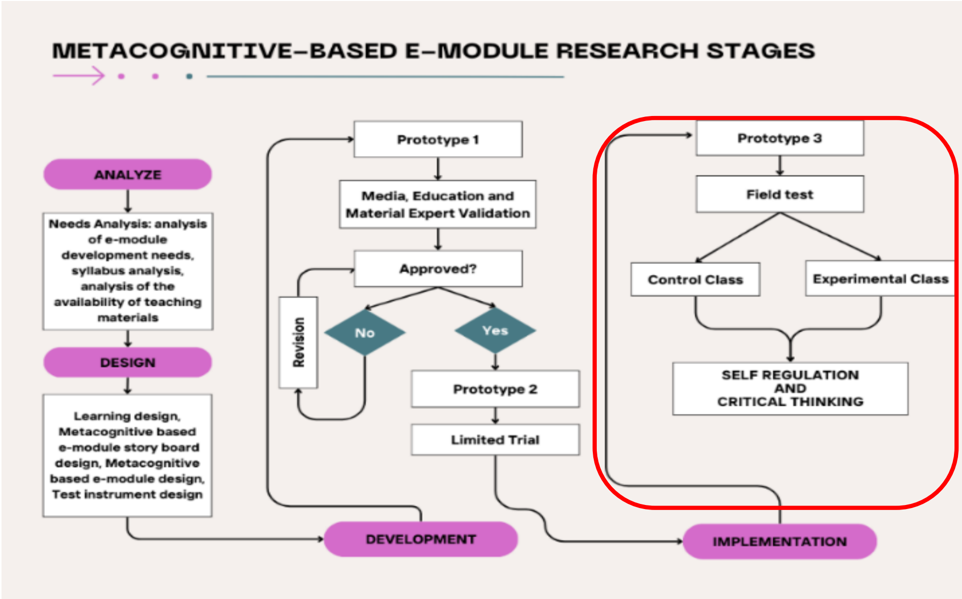
This research is quasi-experimental research that commenced with the development of a learning resource in the form of a metacognitive-based e-module. This was developed using the ADDIE model.

The development of metacognitive based e-module has four stages, analysis, design, development and implementation. The process begins with the analyse stage, the need of analysis conducted evaluating the need for the e-module, analysing syllabus and curriculum requirements, and assessing the availability of existing teaching materials. This basic step ensures that the subsequent design and development are rooted in a clear understanding of the educational context and needs. In the design stage, the focus shifts t creating a detailed blueprint for the e-module. This involves drafting the learning design, constructing a storyboard for the metacognitive based e-module and designing the test instruments. These elements are essential for ensuring that the module not only align with educational standards but also effectively facilitates metacognitive learning strategies.

The development stage begins with the creation of e-module, which undergoes rigorous validation by expert in media, education and material content. In this step, if the e-module is approved, the process moves forward. If not revisions are made until the e-module meets the required standards. Once approved, a limited trial of e-module is conducted to gather initial feedback and make necessary adjustments. This iterative process ensures that the module is refined and effective before broader implementation. The last stage is implementation. In the implementation, e-module is subjected to a field test. This involves dividing participants into a control class and an experimental class. The goal of this phase is to evaluate the module's impact on self-regulation and critical thinking skills among student. The development stages can be seen in Figure 1.

Figure 1

Research stage



The developed module has undergone experts' validation stages which involved professionals in the fields of educational technology, biology education, physiology and molecular genetics. The module validation includes aspects such as content, presentation, layout, graphics, and language. The e-module was validated by four validators: two professors specializing in biology and biotechnology, and two educational technology experts holding a doctoral degree. The module was used for the experimental groups of participants in the Basic Biology lecture. The implementation was carried out with a quasi-experiment Pre-test/ Post-test Control Group Design. To determine the classes for the study, it had initially been approved by both the lecturers teaching the subject and by the students taking part in the course. Respondents were 83 students participating in the Basic Biology course on cell and tissue topics: 41 students in the experimental class and 42 students in the control class. The research design for the experimental class can be seen in Table 1. While the experimental group was engaged in innovative metacognitive e-module activities, the control group was engaged in traditional/non-metacognitive module activities. This approach was taken to ensure a valid comparison between the two groups.

Table 1

Research design

Class	Pre-Test	Treatment	Post-test
Bio Education A (Experiment)	Critical thinking and Self-Regulation Test	Innovative Metacognitive E-module	Critical thinking and Self-Regulation Test
Bio Education B (Control)	Critical thinking and Self-Regulation Test	Traditional/ Non-Metacognitive Module	Critical thinking and Self-Regulation Test

Data Collection

The instruments utilised to collect data were tests to understand students' critical thinking skills and self-regulation, experts' validation sheets and questionnaires from the e-module users and tests to measure any improvement in critical thinking skills and self-regulation of the experimental and control groups.

The test instrument used in the implementation phase consisted of 30 multiple-choice questions, arranged based on indicators of critical thinking (15 questions, with each indicator having 3 items) and self-regulation (15 questions, with each indicator having 3 items). The questions had undergone validation of construct and content (Sumintono & Widhiarso, 2015; Andrich & Marais, 2019). Validation was conducted by three experts in the fields of biology, biotechnology and pedagogy. The validity of the questions based on the infit MNSQ ranged from 0.83 to 1.17 (Valid). Based on the Outfit ZSTD, the validity ranged from -1.59 to 1.85 (Valid). The validity and reliability of question items analysis had been conducted beforehand, as shown in Table 2 below.

Table 2

Critical thinking question items reliability

Construct	Question items	Infit MNSQ	Outfit ZSTD	Measure	Reliability
Critical thinking	S4	1.00	0.45	-0.93	.803
	S20	0.91	0.44	-0.26	
	S24	0.85	-0.72	-2.91	
	S3	1.02	0.20	0.21	
	S16	1.12	1.42	0.92	
	S21	0.83	-0.69	-1.43	
	S5	1.13	1.69	0.68	
	S15	0.97	0.25	1.94	
	S22	0.83	-1.02	-0.93	
	S2	1.09	0.44	0.8	
	S11	1.01	0.22	-0.38	
	S25	0.99	0.14	0.56	
	S8	1.04	1.55	1.6	
	S14	0.95	-0.39	0.21	
	S26	1.08	1.85	1.94	

Table 3 shows the reliability of self-regulation question items. The table includes various statistical measures such as Infit MNSQ, Outfit ZSTD, and Measure, which are used to assess the consistency and accuracy of the self-regulation construct. Each question item is listed alongside its respective reliability scores, providing a detailed view of how well each item performs in measuring self-regulation. The reliability coefficient for the entire set of items is also included to give an overall indication of the test's reliability. This comprehensive analysis ensures that the self-regulation questionnaire is both valid and reliable for research purposes.

Table 3

Self-regulation question items reliability

Construct	Question items	Infit MNSQ	Outfit ZSTD	Measure	Reliability
Self-regulation	S1	1.12	0.82	1.31	.796
	S18	0.97	-0.45	-0.26	
	S27	1.01	0.16	-0.51	
	S10	0.83	-1.59	0.33	
	S13	1.02	0.70	-0.14	
	S30	0.97	-0.05	1.17	
	S6	1.17	1.58	0.44	
	S12	0.85	-0.84	-1.63	
	S28	0.99	-0.38	1.31	
	S7	0.96	0.13	0.10	
	S19	0.89	-0.77	-0.64	
	S23	1.11	0.70	-0.64	
	S9	1.08	0.98	-0.64	
	S17	0.84	-1.27	-0.78	
	S29	0.89	0.13	-1.43	

The questions' difficulty levels or distractors were analysed using the Winsteps 4.5.2 software. Question distribution on the cell, plant tissues, and animal tissue materials consisted of 13% easy questions, 37% in the moderately hard category, 30% in a difficult category, and 20% of the total question very difficult. Hence, it can be deduced that the questions' suitability in this study positively correlated to the difficulty level of questions the researchers had designed on the test item blueprint. There were 6% of questions in the easy category, 40% of questions in the moderate category, 37% in the difficult category, and 17% in the very difficult category.

The result of the distractor quality analysis on the 30 question items indicated that 27 questions out of 30 exhibited satisfactory distractor power, while 3 questions needed revision. Once the questions had been revised, they were implemented in the pre-test and post-tests.

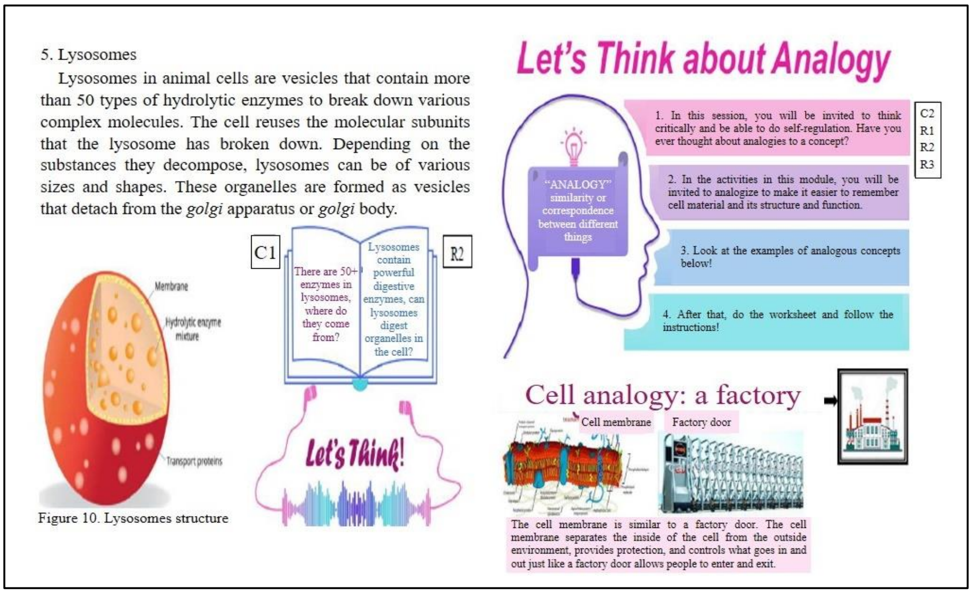
Implementation of Metacognitive-Based E-Module

The metacognitive-based e-module was introduced into the Basic Biology course at the Faculty of Teacher Training and Education, University of Riau. In the control class, the implementation spanned four sessions, each of which lasted 100 minutes. During the first session, a pre-test consisting of 30 items based on indicators of critical thinking and self-regulation was administered for 45 minutes. Subsequently, students were instructed to study independently without access to the metacognitive-based e-module. At the second, third and fourth meetings, learning activities included discussions on cell, plant and animal tissues topics before a post-test was carried out in the last 45 minutes of the 4th meeting given through a Google form.

Likewise, the implementation in the experimental class was also conducted four times, with each meeting lasting 100 minutes. The learning activities, however, were facilitated by online learning platforms Google Classroom, Google Form, and a metacognitive-based e-module on cell and tissue topics. At the first meeting of the experimental class, the lesson started with a 45-minute pre-test through a Google Form encompassing 30 question items based on indicators of critical thinking and self-regulation. In the second, third, and fourth meetings, the lesson was continued using the metacognitive-based e-module (link), measures were taken to ensure that students did not access this module outside of the designated sessions. Learning activities centred on doing tasks independently in the "Let's think" section of the e-module with topics on cells, plant tissue, and animal tissue. There was also a task on an analogy project. The task on the "Let's think" section of the e-module was completed by students using a Google Form.

Figure 2

The "Let's Think" activity based on the e-modul



An additional feature, such as the "Let's Think" activity in the metacognitive-based e-module, has been found valuable for students in the experimental class in stimulating critical thinking and self-regulation. During a scientific debate, students were allowed to present their answers to questions in the "Let's Think" section, each providing different answers and reasons based on scientific references they had read. Researchers then facilitated the discussion, encouraging other students to participate and give their opinions.

Data Analysis

The question items on critical thinking and self-regulation underwent initial testing for validity and reliability, including analysis of difficulty levels and the role of distractors. The validity testing occurred in two stages: (1) construction of the test items by three subject matter experts, and (2) statistical validation of the question items using the Rasch Model. For validity, question items were considered valid if the infit Mean Square (MNSQ) fell within the range of 0.5 to 1.5, and the Z-standard (ZSTD) outfit was between -2.0 and +2.0. The analysis of difficulty levels was conducted using the Rasch model with Winsteps 4.5.2.

The effectiveness of the module was tested by identifying the difference in average scores of pre- and post-test between the experimental and control groups with *t*- test sample using SPSS software version 26 for data analysis.

Findings

Critical Thinking Skills

Table 4 shows presents detailed results on the students' scores.

Table 4

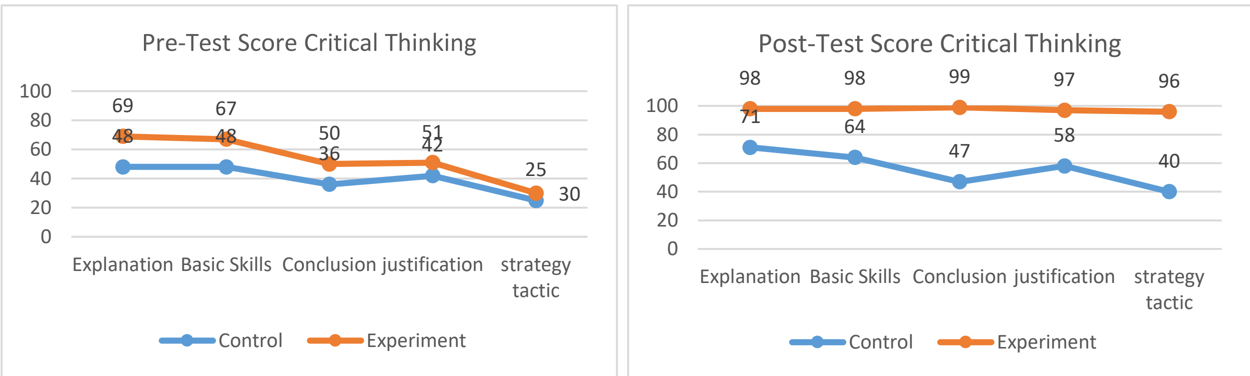
Critical thinking skills descriptive and t-test analysis of pre-test and post test

Factors	Experimental class				Control class			
	Pre-Test		Post-Test		Pre-Test		Post-Test	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Giving a simple explanation	69	25.89	98	7.17	48	29.25	71	26.77
2. Building basic skills	67	24.39	98	7.17	48	28.28	64	30.30
3. Making a conclusion	50	29.53	99	5.14	36	26.01	47	26.34
4. Giving further justification	51	27.61	97	8.67	42	27.24	57	33.34
5. Setting strategies and tactics	30	26.32	96	10.90	25	29.12	40	30.17
Total Mean	53.41		97.83		39.88		56.24	
T	-15.632				-4.714			
P	.001				.001			

The average score on each factors of the pre-test and post-test increased substantially. The highest score difference between the pre-test and post-test was on the students' ability to set strategies and tactics. This implies that students' skills in arranging strategies and tactics grew significantly after using the metacognitive-based e-module. It can be seen from the table that experimental class (t=-15.632) and control class (t= -4.714) each significant value (p-value < 0,05). This suggests a noteworthy difference in students' critical thinking skills before and after the implementation of the metacognitive-based e-module.

Figure 3

The average score of critical thinking skills pre- and post-tests



Self-Regulation

Students' self-regulation was inferred from how the students were aware of their thinking, how they obtained information from different sources, how they respond and give feedback, and how they evaluated and planned effectively. The following are the descriptive data on students' self-regulation in the pre-test and post-test.

Table 5

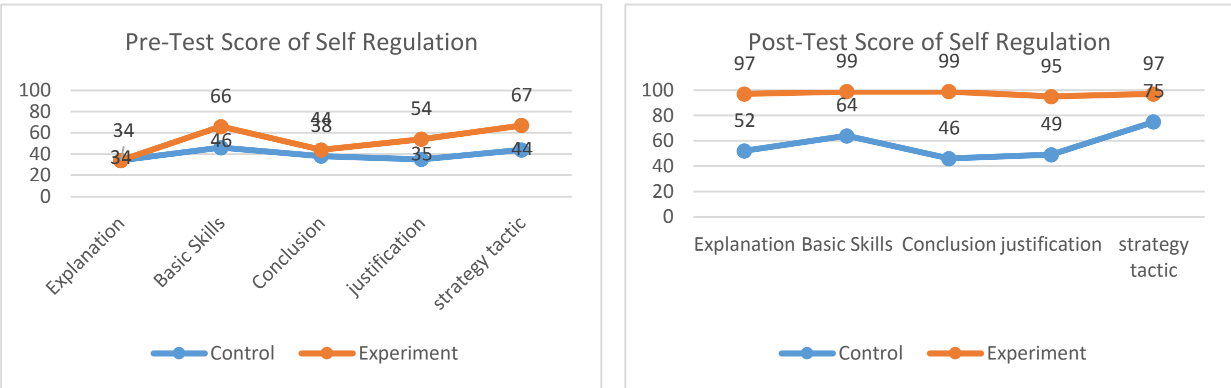
Self-regulation descriptive and t test analysis of the pre-test and post-test

Factors	Experimental class				Control class			
	Pre-Test		Post-Test		Pre-Test		Post-Test	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Aware of one's thought	34	27.01	97	8,67	43	27.66	63	21.57
2. Aware and use the necessary sources of information	66	30.76	99	5,14	61	21.70	67	28.14
3. Sensitive to feedback	44	21.37	99	5,14	36	21.57	45	21.58
4. Evaluate the effectiveness of one's action	54	29.31	95	13,88	55	22.59	63	28.89
5. Plan effectively	67	31.20	97	8.67	28	30.76	65	28.01
Total Mean	52.85		97.66		38.38		55.48	
T	-16.595				-5.053			
P	.001				.001			

The average score on each indicator of the pre-test and post-test increased considerably. The highest increase in self-regulation was found in the students' sensitivity to feedback. From the table, it is evident that there were differences in self-regulation between the experimental class (t = -16.595) and the control class (t = -5.053) (p-value < 0.05). This difference indicates a change in the average score of students' self-regulation before and after the implementation of the metacognitive-based e-module. In conclusion, the metacognitive-based e-module is indeed suitable for improving students' ability to think critically and regulate themselves effectively.

Figure 4

The average score of self-regulation ability pre- and post-tests



Discussion

The goal of this study was to scrutinise the increase in first-year university students' critical thinking and self-regulation by implementing a metacognitive-based e-module. The results disclosed a substantial rise in the post-test average score of those students using the metacognitive-based e-module compared to their counterparts who did not use it. The differences observed between the experimental and control groups suggest that the metacognitive-based e-module effectively promotes students' ability to think critically and regulate themselves. By emphasizing metacognitive skills such as planning, monitoring, and evaluating, the e-module encourages students to take control of their learning processes.

Students' Critical Thinking

Three models namely discrepant events, analogy, and mnemonic were selected to integrate the metacognitive strategies into the e-module. The discrepant events was presented in the form of "content material boxes" containing facts that likely prompt assumptions from students, thus provoking critical thinking. The activity was designed in a way that can elicit students' curiosity. This kind of activity can help students develop a more scientific mindset. When students observe something that provokes their curiosity, it will lead to investigations or research. This is specifically what is meant by the enquiry which develops reasoning skills, problem-solving, and self-regulation. This type of activity aligns with the concept of inquiry-based learning, which is known to promote deeper understanding and critical thinking. By engaging in such activities, students are not only learning content but also developing important cognitive skills necessary for their academic and professional growth.

In the experimental class, the students responded to the discrepant events activity enthusiastically. They were driven to recheck the truth of the facts presented and some were passionate to share unique facts they had just found from reading different scientific sources. Others were motivated to explore the materials in the e-module. Thus, it is evident that integrating discrepant events into the metacognitive-based e-module can stimulate students to think critically. An illustration of this is when the students rechecked the truth of presented facts. Verifying the truth of issues or facts can cultivate students' reflective skills and awareness of their knowledge (metacognitive) (Setiawati & Corebima, 2018).

This finding is in line with the research result conducted by Hastuti & Sutarto (2017) who discover that the metacognitive approach to discrepant events can improve university students' higher-order thinking. Another study found that there were significant differences in metacognitive skills, particularly in the aspects of declarative, procedural, and conditional knowledge. Setiawati & Corebima (2018) found that metacognitive skills can enhance knowledge acquisition and positively influence student learning outcomes. In our study, integrating metacognitive strategies like analogy and mnemonic in the e-module has similarly shown promising results in improving students' critical thinking and self-regulation. Furthermore, there is a positive correlation between metacognitive skills and students' critical thinking skills (Rivas et al.,). Students with high metacognitive strategy statistically have a significant difference in critical thinking contrasted to their peers with low metacognitive strategy (Mohseni et al., 2020). Longfield (2009); Scheiner (2020) affirms that discrepant event concretises abstract concepts. The ability to think critically, develop metacognitive skills and express opinions are the skills students must have in studying. Metacognitive awareness is essential in enhancing critical thinking skills such as organizing tasks, designing strategies and the ability to analyse weaknesses and strengths in task completion (Maksum et al., 2022).

As for the analogy model, it has been shown to increase students' understanding of concepts in physics, with the average score 55.4 on the pre-test and 77.0 on the post-test (Djudin & Grapragasem, 2019). The use of the analogy model can also reduce misconceptions in physics (Djudin & Grapragasem, 2019). The metacognitive-based e-module assists students in comprehending learning materials that are difficult to visualize through the analogy model and interactive videos. The selection of media and learning models can significantly influence students' critical thinking abilities. According to Annisa (2020), media play a crucial role in education and the social realm, as virtual learning environments integrate information, communication, collaboration, learning, and management. These findings underscore the importance of integrating effective media and learning models to enhance students' critical thinking skills and comprehension of complex concepts.

The analogy enables students to create metaphors and visualise learning materials such as associating cells with a factory or comparing the transport tissue system in plants to the circulatory system or likening the multi-layered flat epithelial tissue to the epidermal tissue in plants. In this study, students in the experimental class passionately presented their analogy project. They were actively discussing the analogies they had made supported with reasons or scientific information in terms of structures, functions, or how an object works. This activity integrated into the metacognitive-based e-module can then arouse critical thinking in students and allow them to regulate themselves to create metaphors or visualization so that learning material is easy to be understood. Yuningsih & Susilo (2018) assert that the metacognitive analogical concept is often associated with conceptualisation, which is a part of higher-order thinking skills. The research result of a study conducted by Yuningsih & Susilo (2018) found that the application of the analogy model acts as a bridge to understand materials that are complex to visualize by students through phenomena or objects around them. The use of this analogy model or concept is not limited to the materials of concepts but can also be used to explain a process or a structure of an object. Overall, comparing two similar things using this analogy approach very likely helps students to better remember the materials they learn.

Lastly, integrating a mnemonic model in a metacognitive-based e-module is believed to help memory performance to remember a concept through long-term memory encoding in an exciting way. Some examples of the topic that can be studied using mnemonics are plant cell structure, root structure, meristem tissue classification based on its origin of formation and position, the function of epithelial tissue and its classification in animal tissues, grouping cell organelles based on the membrane, and mnemonic about organelles that are only possessed by animals or plants. Similar to the *discrepant event* and analogy model, students in the experimental class responded positively to this mnemonic technique. Some of them were eager to share the concise and humorous mnemonics they had created so that the learning situation became lively as it triggered other students to share their mnemonics. This pleasurable but meaningful activity can stimulate critical thinking and self-regulation in students. For instance, a mnemonic model such as CAMSEA, which stands for Cnidarians, Annelids, Molluscs, Sponges, Echinoderms, and Arthropods, was found to be particularly effective in helping students remember these animal groups (Lubin & Polloway, 2016). The positive impact of these metacognitive strategies on critical thinking skills is supported by previous research. (Nori et al., 2019) found that such strategies can improve students' study outcomes across cognitive, psychomotor, and affective domains.

Students' Self-regulation

The students' self-regulation in the experimental class was significantly influenced by the implementation of the metacognitive-based e-module. The module was designed to train students' self-regulation, particularly in responding to feedback. For instance, in studying the concept of cells, students were prompted with the "Let's think" section, which stated that there are more than 50 enzymes in lysosomes. This type of question stimulates students' self-regulation by making them sensitive to feedback, as they are initially given insight into the number of enzymes in lysosomes and then asked to analyze the origin of these enzymes.

Another example occurred in a lesson about plant tissues. Students were asked to analyze the type of tissue based on given characteristics. This type of question requires students to work independently, allowing teachers to assess their sensitivity to feedback and their ability to regulate themselves in finding answers. These activities foster self-regulation by encouraging students to observe, evaluate, and respond to their learning process.

The impact of these activities is consistent with previous findings that highlight the importance of self-regulation in academic success. Self-regulation enables students to adapt flexibly to changing demands, leading to improved learning outcomes. The results of this study align with the research of Baumeister (2018), which emphasize the role of self-regulation in achieving desired goals and adapting to various life situations.

The additional feature of "Let's think" also facilitates students in the experimental class to regulate them. When presenting their answers to the questions in the "Let's think" section, for example, there was a scientific debate among the students due to different assumptions of the correct answers. In response to the debate, the research team encouraged other students to participate in sharing opinions and the team clarified the correct answers afterwards. This typical activity is very conducive and effective to stimulate students' critical thinking and self-regulation. Another justification for the increase in critical thinking and self-regulation is the use of the metacognitive-based e-module with its various advantages. The module's interactive design with images, audio, video and formative tests allows immediate and automatic feedback. This interactive and engaging approach helps maintain students' interest and encourages them to reflect on their learning processes, thereby enhancing their self-regulation skills.

The integration of metacognitive strategies in the e-module also facilitated scientific debates among students, which further stimulated their critical thinking and self-regulation. This interactive approach encouraged students to reflect on their learning processes and share their insights, leading to a more engaging and effective learning environment. The findings of this study align with the literature that highlights the strong link between metacognition and critical thinking (Abdelrahman, 2020; Block & Russell, 2012; Mohseni et al., 2020; Oflaz, 2021; Pradhan & Das, 2021; Rivas et al., 2022; Rosdiana et al., 2023; Sinar, 2018; Sutama et al., 2022). These metacognitive strategies not only accelerated the development of students' critical thinking skills but also improved their self-regulation, making the metacognitive-based e-module a valuable tool in enhancing both cognitive and metacognitive abilities.

Inferential analysis through a t-test was conducted to observe the improvement of critical thinking and self-regulation in this study, based solely on the N-gain of pre-test and post-test scores. The t-test results indicated significant differences in the scores, confirming the effectiveness of the metacognitive-based e-module in enhancing both critical thinking and self-regulation among students. This statistical evidence supports the qualitative observations of increased engagement and reflective thinking, further validating the positive impact of metacognitive strategies on student learning outcomes.

Conclusion and Implications

The integration of a metacognitive strategy in developing a learning source in the form of an e-module can increase first-year students' critical thinking and self-regulation. Implementing the metacognitive-based e-module supports the students in understanding materials that are difficult to visualize with the help of the analogy model and interactive videos. Meanwhile, the mnemonic technique assists students in learning by strengthening long-term memory performance in an enthusiastic way. Additional feature such as "Let's think" is also beneficial for those in the experimental class to ponder analytically and control themselves.

However, this study was limited to two topics only (cells and tissues) in the Basic biology course. Gathering respondents and monitoring students' activity in answering the questions and tasks given online requires certain techniques and more intensive observation compared to face-to-face learning. The availability of self-learning resources that can be used anytime and anywhere will provide convenience for students to access information. This will also have implications for empowering students' potential in learning and completing tasks in higher education.

Further research is expected to expand the implementation to cover at least eight topics or more. Additionally, future studies could be conducted in blended learning environments on a larger scale, involving a more diverse group of participants. This approach could provide a broader understanding of the effectiveness of metacognitive strategies across various subjects and learning contexts.

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A professional development programme based on biomimicry to improve stem project creativity of science student teachers

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ABSTRACT
In Thailand, science, technology, engineering and mathematics (STEM) education is being promoted to support science student teachers by conducting projects to extend their learning skills and to turn them into innovators. This study aimed to develop a professional development programme (PDP) based on biomimicry to improve STEM project creation for science student teachers and to evaluate the implementation result of this programme. The 60-hour programme, designed for 29 science student teachers from a teacher training institute in southern Thailand, was collaboratively developed to align with stakeholders' needs. It comprised four main lessons incorporating biomimicry principles and an eight-step problem-solving approach. The design process included stakeholder input, expert validation, and iterative improvement. The PDP integrated a coaching approach to facilitate problem synthesis and enhance learning outcomes. It underwent multiple stages of design, drafting, and expert validation before finalization. The programme's effectiveness was evaluated through the creativity of resulting STEM projects using class observations, a creativity evaluation form, and interviews. Data analysis employed content analysis and interpretatiove methods. The implementation resulted in six innovative biomimicry-inspired STEM projects, demonstrating the programme's success in fostering creativity and innovation among future educators. This study contributes to the advancement of STEM education in Thailand by providing a structured approach to developing science student teachers' project creation skills.

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Introduction

Interdisciplinary STEM education refers to an education approach that integrates science, technology, engineering and mathematics. It encourages students to connect concepts across these disciplines, fostering a holistic understanding (Cinar et al., 2022). STEM education is increasingly vital across all educational levels, from primary through tertiary, as it develops critical thinking and problem-solving skills beneficial in various fields. While STEM careers, including healthcare, are projected to expand more rapidly than non-STEM jobs, the skills acquired through STEM education are valuable in all career paths. Hands-on projects in STEM courses teach time management and project breakdown skills, applicable to various life and career tasks (Yeti Academy, 2024). The importance of this integrated approach to STEM education (Sanders, 2009) is being increasingly recognised worldwide, including in Thailand. Recent shifts in STEM education have led science instructors and educators to focus more on design-based learning, which integrates scientific inquiry with engineering practices to promote meaningful learning experiences (Ladachart et al., 2022).

The Thai government's policy is to improve its manpower for STEM education (The Institute for the Promotion of Teaching Science and Technology [IPST], 2020; Office of the Basic Education Commission, 2008) by encouraging learners to conduct innovative projects and by training professional teachers for STEM education. Toward this end, the Ministry of Education is constantly promoting STEM education as a core component of the curriculum to drive innovations in science and technology and to develop society and the economy (IPST, 2020; IPST, 2022). The main challenge in delivering STEM education is the availability of suitable STEM teachers (Bybee, 2010). Professional STEM teachers with necessary skills are required to design learning activities that can increases a learner's potential. Therefore, STEM project management should contain high-quality professional development experiences to learn how to design learning activities (Capraro & Slough, 2013). Most previous projects by Thai students lacked interdisciplinary integration, often focusing on single subject areas rather than combining methods or tools from different sciences (Chongsrid, 2016).

Although the Thai government is promoting STEM education, insufficient training is available for both pre-service and in-service STEM teachers in universities (Pimthong & Williams, 2018). Therefore, comprehensive training is needed to ensure STEM teachers are proficient in STEM knowledge, teaching methods, and skills. This training should occur during student teacher preparation (Shernoff et al., 2017) and continue through in-service professional development for practicing teachers. Science student teachers play a significant role in constructing and publicizing STEM education for science teaching (Djulia & Simatupang, 2021). Preparing for STEM teaching in a given subject is one approach for ensuring that both student teachers and current educators have the necessary preparation to effectively implement STEM education in their classrooms (Mafugu et al., 2022).

Biomimicry is an important approach to encourage students' creativity and enable successful STEM projects; it involves emulating nature to create new things or processes to resolve complex real-world problems (Benyus, 2002). Biomimicry affords advantages that are suitable for STEM interdisciplinary learning (Pauls, 2017). Biomimicry involves selecting a problem, looking for a plant or animal that faces the same problem, and emulating its solution for solving the problem, thereby learning from nature (Nilsart, 2016). It is an educational revolution that integrates biological sciences, STEM education, creative solutions, designs and systematic thinking to inspire learners. Biomimicry can be incorporated into science education for many topics including STEM education and environmental studies (Baumeister, 2013). The learner can innovatively solve a real-world problem by emulating a natural process or discovering data from nature. By doing so, the learner will develop their knowledge and competencies in STEM and related fields, including creative disciplines such as design, architecture, and applied arts (Coban, 2019). This approach, especially when supported by scientific inquiry, is useful for developing a learner's design and systematic thinking skills (Qureshi, 2020). Thus, it allows learners to connect theories and scientific knowledge to daily life and to create learning for sustainable development. Further, it builds an understanding and awareness of the value of natural resources in terms of their benefits to and significance for humans, and it will contribute toward innovation and technological developments that are mindful of the environment (Putwattana, 2018).

Currently, no guidelines have been established for an instructional process that contributes to encouraging innovation in learners' STEM education in response to existing problems. Many teachers struggle to integrate STEM education and the engineering design process into their daily instruction (Xue et al., 2023). Thus, teacher training institutes should study and develop the teaching profession to train effective STEM teachers who can conduct STEM projects and play new roles in our evolving society, contributing to the necessary developments in national education. This study aims to develop a Professional Development Program (PDP) to enable science student teachers to use biomimicry to improve their STEM project skills and to study the implementation results of this program.

Accordingly, the following research questions guided the study: What is the structure of a PDP that enables science student teachers to use biomimicry to improve their STEM project skills? What is the impact of the developed program on the STEM projects of science student teachers?

Literature Review

STEM Education and the Drive for STEM Education in Thailand

STEM education was first implemented by the National Science Foundation (NSF) in 1990. It is a teaching and learning approach in which STEM knowledge and skills are applied to solve real-world problems (Bozkurt et al., 2019; Sanders, 2009). In Thailand, the Ministry of Education is promoting STEM education through the Institute for the Promotion of Teaching Science and Technology (IPST), whose aim is to enhance the science, mathematics and computer skills of Thai teachers and youths. Since 2013, IPST has promoted STEM education by establishing the national STEM education centre, constructing the STEM cooperation network with the Office of the Basic Education Commission (OBEC) to develop teachers, and, in 2014, initiating the Outstanding Teacher Award for STEM Education. STEM education has been made a core component of the education curriculum for B.E. 2560–2579 (CE 2017–2036) (IPST, 2022). However, despite these efforts, STEM education in Thailand faces challenges in fully developing learners' critical thinking and problem-solving skills, as reflected in international assessments such as the Programme for International Student Assessment (PISA). For example, Thailand has scored lower than the international average in science and mathematics, which may indicate a need for more effective STEM instructional practices and resources (PISA Thailand, IPST, 2019).

STEM Education Project based on Engineering Design Process

Project-based learning has long been used in fields such as medicine, engineering, education, economics and business (Capraro & Slough, 2013). STEM-project-based learning is a learning approach that has been developed for delivering STEM education and preparing learners to keep up with technological advancements (Lou et al., 2011). It challenges and encourages learners' critical and analytical thinking skills and promotes advanced thinking through cooperation, communication, problem-solving, and self-learning (Baran et al., 2021; Capraro & Slough, 2013). A STEM project involves efficiently using STEM knowledge, methods, and resources to solve real-world problems and to achieve desired outcomes. The teacher's role in STEM-based instructional management is to guide the learner to find a solution. The teacher acts as a coach or instructor who monitors the progress of the project and ensures that everyone cooperates to achieve the common goal. Learners can independently discuss, experiment with, and apply their methods to solve the problem (Sahin, 2013). The STEM-project-based learning design process begins with clearly determining the expected outcome by establishing the objective and planning the project evaluation result summary. The learner is assigned tasks to present ideas for resolving complex problems, which is typically effective at the upper secondary level or higher, as it requires advanced problem-solving and critical thinking skills (Capraro & Slough, 2013).

Biomimicry as a New Approach to STEM education

The term "Biomimicry" has roots in ancient Greek; "Bios" means life, and "Mimesis" means emulation. Therefore, "biomimicry" means emulating organisms in nature (Wangtreesup, 2017). Biomimicry is an interdisciplinary field that combines ecology, technology and other fields to solve problems using knowledge of biology. Biologists, engineers, architects and designers in the educational and industrial sectors are adopting biomimicry for various design purposes (Jacobs et al., 2022). Biomimicry can be applied at three levels to solve problems: the organism level (emulating the form and function of specific species), the behavioural level (mimicking how organisms behave or interact), and the ecosystem level (replicating complex systems of interdependent species) (Pathak, 2019). Biomimicry has been observed, learnt from, and emulated in many cases to create innovations. For example, the structure of lotus leaf surfaces has inspired the development of water-repellent materials, and the shape of the spiral impeller, inspired by the structure of an apple snail shell, has been used to reduce energy consumption in impeller drives.

Scientists apply biomimicry through two main patterns. The first pattern involves identifying a problem, analyzing it, and then finding an organism that has developed a solution to a similar issue, which can be emulated for innovative problem-solving. This is called the top-down approach. The second pattern begins with a scientist gathering data from nature by identifying the features, behaviours, or functions of an organism or ecosystem. This leads to the construction of knowledge and understanding of the organism's self-adaptive mechanisms, ultimately resulting in the development of novel technology.This is called the bottom-up approach (Pathak, 2019). Many studies have applied biomimicry as an alternative to STEM education. For instance, Bilici et al. (2021) allowed students to work as engineers to design an ecofriendly vehicle prototype to mitigate air pollution; this was inspired by the human body system and the movement of the grasshopper, ant, spider, and red Japanese beetle. Coban and Costu (2021) applied biomimicry to allow students to select an organism and to then develop their ability to observe living things, understand the relationship between its structure and function, and design and create a model. Gencer et al. (2020) developed a STEM activity by using biomimicry in the design process to search for the relationship between the structure and function of organisms and to integrate a learning unit of organisms on earth. Pongsophon et al. (2021) examined the development of teachers' understanding of the engineering design process through a biomimicry workshop on design in consideration of environmental and social impacts (i.e., green design). Qureshi (2020) investigated biomimicry with undergraduate students who used it to create innovate designs for healthcare challenges.

Research Design and Methods

This study employed an interpretative paradigm and a qualitative research method. The primary aim was to develop and evaluate a professional development program (PDP) based on biomimicry to enhance STEM project creativity among science student teachers. The research design focused on the program development process, its implementation, and assessment of its effectiveness. The study comprised three main phases:

1. Program Development: Designing the PDP based on biomimicry principles and stakeholder input.
2. Implementation: Conducting the program with science student teachers at a teacher training institute in southern Thailand.
3. Evaluation: Assessing the impact of the PDP on the STEM projects created by participants.

This approach emphasizes the program's development and efficacy rather than treating it as a conventional study on learners and learning outcomes. For reference, student teacher teams and individual student members are represented using the abbreviations T and S, respectively, along with numbers (e.g., T1 for the first team, S1 for the first student teacher).

Programme Development

The proposed PDP was designed to align with the needs and expectations of multiple stakeholders: the university supervisor, supervising teacher, and student teachers, as well as the new state education policy. Its primary goal was to improve the STEM project creativity of science student teachers. The programme's objectives, content, main activities, and structure were developed collaboratively, incorporating input from all these stakeholders. Information gathered from focus group discussions with them was instrumental in shaping the program design. The programme was designed and delivered using a constructivist approach, with key components including pedagogical theory, content knowledge, activity practice sessions, discussion, reflection, and action (Loucks-Horsley et al., 1998). It was designed to allow science student teachers to participate for 60 h. It consisted of four main lessons: (1) basic knowledge about biomimicry; (2) a case study of strategy development for creative designs inspired by nature and natural patterns; (3) biomimicry innovation: a challenge of designing a flying machine; and (4) biomimicry innovation: being inspired by nature for engineering problem-solving and innovative product design in STEM projects. The researcher applied a biomimicry principle based on "biology to design a spiral" (Macnab, 2012) and modified it to suit Coban's (2019) approach to solve problems. It included eight reversible steps:

(1) Identifying the problem: Identify a need to satisfy or problem to solve, and then find living things facing similar problems and imitate their methods for solving the problem.

(2) Obtaining data from nature: Link the observed relationships between the processes and functions of living things and discovered data to gain knowledge and understanding of the adaptation mechanisms of living things, and use these as inspirations for design.

(3) Emulating: Students are inspired by living things to find technological design ideas.

(4) Designing: Students create designs inspired by living things through drawings and three-dimensional models.

(5) Exchanging: Students share design ideas through simulations with fellow students and STEM subject matter experts, including engineers, mathematicians, scientists, technologists, and materials scientists.

(6) Prototyping: Students create a prototype, which is a model or preview of the final product, and forward it to the development team for the next step in the development process.

(7) Testing: Students test the use of the prototype to solve problems. The test results may be used to improve and develop the prototype to solve the problem more effectively.

(8) Evaluating: Students evaluate the use of the prototype to solve problems.

The evaluation results may also be used to improve and develop the prototype to solve the problem more effectively. The program incorporated a coaching approach for synthesizing problems. A coach participated in the problem-solving process or promoted learning to enable the success of the STEM project. The PDP was developed through design, draft, and quality validation (by experts) stages; improved; and finalized.

Description of Biomimicry STEM Lessons and Implementation

Twenty-nine science student teachers from Rajabhat University in southern Thailand voluntarily participated in the PDP. The study was conducted for 60 h during the science method course (4 h per day, 1 day per week) in the first term of academic year 2022. This structure was based on the university's standard credit system and curriculum design guidelines. Each participant received three graduate credits from the university for participating in the PDP, aligning with the institution's credit allocation policy. The programme was conducted through discussions, collaborative group work, hands-on activities, problem-solving opportunities, reflections, and presentations by the participants (Loucks-Horsley et al., 1998). The lessons on using biomimicry for solving problems were divided into four major parts, as described below.

Part 1: Basic Knowledge about Biomimicry (8 h)

The first part of the lesson aimed to introduce basic knowledge of biomimicry and how nature inspires humans to design products and technologies.

Activity 1: Reflect on design by observing the structures and functions of specific organisms, such as the vein patterns in leaves, and encourage thinking through questions such as (1) What do you see from this pattern? (2) What is the specific purpose of the venation? (3) Where else can we find this pattern in nature and why? (4) How does the water transport system in plants differ from the systems designed by humans?

Activity 2: Recognise the design principle and key strategy used in nature through a case study of biomimicry and conduct the biomimicry mix and match activity (CERES, 2024) to match the invented product inspired by nature (plants or animals). Reflect through questions such as (1) What is the matching biomimicry project, and which organism inspired the product (e.g., the shape of a kingfisher's beak inspires the design of bullet trains)? (2) What is the positive environmental impact? (3) What is the positive impact on individuals and society? (4) Can the design be improved, and if so, how?

Activity 3: Survey the natural environment in the university to observe the characteristics or patterns of designs and analyse their purpose.

Part 2: Case Study of Strategy Development for Creative Design Inspired by Nature and Natural Patterns (20 h)

The second part of the lesson aimed to develop strategies to produce creative designs inspired by nature (STEM Learning Ltd., 2018).

Activity 1: Apply morphing, a special technique that involves changing an image to a material or practice, as a strategy for creative thinking (8 h). Study the case of Alessi, an Italian company that makes houseware and kitchen utensils by using morphing. The sample is the student's project of using the pattern of a large honeycomb and a glass with a pipe to develop a new product, namely, a 2-in-1 pipe glass for drinking in which the pipe is a handle or straw (Figure 1).

Activity 2: Concept of creative textile/fabric design inspired by nature (8 hours) to explore how biomimicry influences textile design and practice. The sample is a student project based on a textile/fabric design inspired by a peacock (Figure 2), demonstrating how natural patterns and forms can serve as a source of inspiration for creative textile designs.

Activity 3: Creative architectural design inspired by nature (4 h) to understand how biomimicry inspires architecture via shapes and patterns through a video.

Figure 1

Pipe glass morphing design (S26)

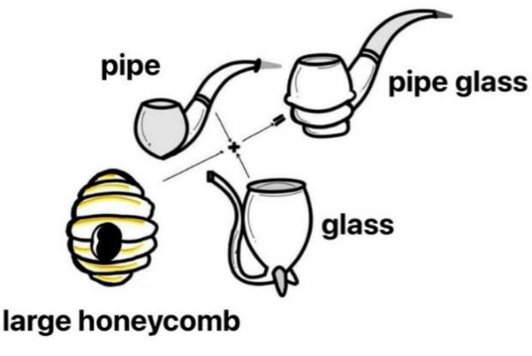
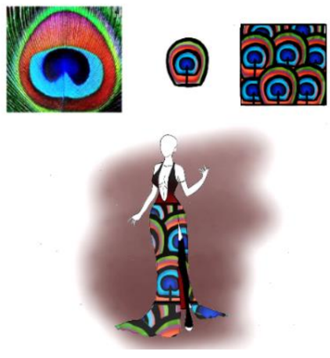


Figure 2

Textile/fabric design from peacock pattern (S3)



Part 3: Biomimicry Innovation: A Challenge of Designing a Flying Machine (12 h)

The third part of the lesson aimed to enable students to perform biomimicry by creating a flying machine based on the eight reversible steps of biomimicry: (1) identifying the problem, (2) obtaining data from nature, (3) emulating, (4) designing, (5) exchanging, (6) prototyping, (7) testing, and (8) evaluating.

Activity 1: Review the biomimicry lesson. Learn the work background of Leonardo da Vinci, who tried to invent a flying machine by observing a flying bird. Students will work in small groups of 4–5 and must research information about suitable flying animals to emulate, design a sketch, and build a model. For example, figure 3 shows how a student team created a flying machine by emulating a flying greater coucal and tested its performance for prolonged flight duration.

Figure 3

*Flying machine emulating a flying greater coucal (T*3)

Part 4: Biomimicry Innovation: Inspiration from Nature for Engineering Problem-Solving and Innovative Product Design in STEM Project (20 h)

The fourth part of the lesson aimed to enable students to create biomimicry STEM projects inspired by nature to solve engineering problems and to develop innovative product designs.

Activity 1: Students are divided into six teams of 4–5 to create STEM projects. The activity is conducted according to the biomimicry guidelines. First, students identify the problem to solve or need to satisfy. Then, students work as a team to find an inspiration to solve this problem by observing a plant or animal, understanding the function of its structure, and using its structure and function to produce a product blueprint to solve the real-world problem. Finally, students propose the solution to experts from various disciplines and answer questions reflecting STEM knowledge: (1) What scientific knowledge do you apply to emulate the organism's structure, and what is the structure's function? (2) What equipment, tools, materials, or processes do you use to solve the problem? (3) What are the problems that the invented innovation can solve? How does the innovation better solve the problem compared with the existing solution? (4) Did you apply a creative scientific principle to design and develop the innovation based on the purpose of use, worthiness, and safety? (5) Did you use mathematics to explain and study the relationship, and if so, how?

Evaluation of PDP

The effectiveness of the PDP can be evaluated through the STEM project creativity of the science student teachers. Data were collected through the observation and STEM project creativity evaluation form and semistructured interviews of selected participants. The form was used to evaluate the creativity as a result of their participation in the program. This form was improved based on the study by Gencer et al. (2020). It focuses on eight categories that represent students' progression from level 1 to 3, and it provides an analysis of the engineering design process. The form was created to evaluate the prototype biomimicry models developed by students to solve a human problem. The students should be able to explain how they design the STEM project, structures of the organisms that inspire them, and how the structure's function is used to solve the real-world problem. Further, they have to answer questions that reflect their STEM knowledge. Finally, the participants were interviewed. The interview questions focused on factors that support and obstruct the programme implementation.

Data Analysis

The observation and STEM project creativity evaluation form was analysed and scored using a key created for this study. The form was used for assessing students and their STEM project creativity after each group presented. Content analysis was conducted to analyse the data obtained from the form. All data were classified. The data were interpreted to obtain an inductive summary classified by the content before comparing the contents.

The interview data were aggregated based on the response homogeneity or heterogeneity (Patton, 2002). Structural coding and inductive analysis were used to analyze the data arising.

Trustworthiness of Findings

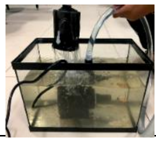
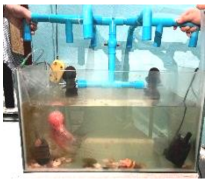
To make the research reliable based on the concept suggested by Lincoln and Guba (1985), the researcher took the following steps: engagement with the participants was prolonged to 60 h to ensure that useful data were acquired, and methodological triangulation was performed to recheck whether different data collection methods provide the same or different results. The data were interpreted after they were validated by an expert.

Result of PDP Implementation

The implementation of the Professional Development Program (PDP) demonstrated successful outcomes, as evidenced by the engagement of participants in creating STEM projects using a biomimicry model. The participants could engage in a STEM project with a biomimicry model. The researcher assigned students to work in six teams of 4–5, with each team creating one STEM project. The results revealed that each team created inventions derived from biomimicry principles: Team T1's a hydropower plastic bottle compressing machine, Team T2's a plant nursery, Team T3's an automatic trash can – EM trash can, Team T4's SCTH drone – simulating the transport of a first-aid kit, Team T5's fish stool suction, and Team T6's an oxygen pump in a fish tank. Each innovation was designed by imitating living things to solve different human problems. The participants began by analysing the problem to solve and then finding an organism facing a similar problem to emulate its solution. Then, they obtained data from nature to link the structure and function of the organism to acquire knowledge and understand the adjustment mechanism that inspired their design. They emulated the selected organism to look for technological design concepts and designed the work creatively by using drawings and 3D models. They exchanged and shared their idea via the model with peers and STEM experts, including biologists, mathematicians, technologists, materials scientists, and engineers. Then, they created the final model and tested whether it could solve the problem. The test result was applied to improve and develop a more efficient solution. The participants also evaluated the use of the model. The innovation projects produced by each team are summarized in Table 1, which provides an overview of the biomimicry-based solutions and the corresponding inspiring organisms, structures, and functions that were emulated.

Table 1

Innovation projects or STEM-based solutions developed using biomimicry

Team	Innovation/Problem-Solving method	Inspiring organism	Organism structure and function	Solution
T1 Hydropower plastic bottle compressing machine		Python	Python's body – Prey behavior by squeezing with the body.	Minimize the storage space required before recycling.
T2 Plant nursery		Mangrove and Snapper	Mangrove's root supports the trunk. Snapper scale prevents concentrated minerals in the ocean from permeating to the body.	Control and set an appropriate environment for plant growth.
T3 Automatic trash can - EM trash can		Nepenthes	Trap and digest insects – when insect sits on a bag mouth, it will drop into the bag and be digested by the digestive juice.	Reduce the littering problem and use food waste to produce organic fertilizer.
T4 SCTH drone – simulating the transport of first-aid kit		Dragonfly	Flying – vertically by lifting up or down and forward.	Control a drone to transport a first-aid kit in various situations.
T5 Fish stool suction		Sucker catfish	Mouth – small teeth scratch animal tissues or moss from surfaces to eat.	Remove moss and fish stool in a fish tank.
T6 Oxygen pump in a fish tank		Mudskipper	Tail fin – jump on the water surface by rolling the lower tail and springing. Movement - use a pectoral fin to crawl on sludge to support itself.	Solve the problem of insufficient oxygen in water, save water by reducing need for changing water in a fish tank, and save electricity.

For evaluating the creativity of each team's biomimicry-based STEM project, the researcher evaluated the engineering design process in terms of eight components, each scored with 1–3 points, by using the evaluation form adapted from Gencer et al. (2020). The results showed that the students achieved a moderate average score of 2.41, which accounted for 80% of the total possible score (Table 2).

Table 2

Results of designing innovative inventions to solve problems.

Component	Criteria	$\bar{X}$	SD	Skill Level	%
Identifying demand or problem	Understand real-world problem and identify needs	2.83	0.37	Good	94
	Determine the criteria and limitations	1.83	0.37	Moderate	61
Researching demand or problem	Identify necessary information for a solution or demand	2.67	0.47	Good	89
	Determine the use of acquired information to solve a problem	2	0	Moderate	67
Developing a possible solution	Propose solution guidelines	2.67	0.47	Good	89
	Draft blueprint of the proposal	2.5	0.5	Good	83
Selecting the best solution	Consider pros and cons of proposed solution	2	0.82	Moderate	67
	Explain reasons (positive or negative criteria and limitations) for selecting the best solution	2	0	Moderate	67
Creating a model	Create a model or prototype of the solution by explaining and giving the details	2.5	0.5	Moderate	83
	Use materials that meet the criteria and limitations of the model or prototype	2.33	0.73	Moderate	78
Testing and evaluating solution	Test how the model or prototype solves the problem or need	2.17	0.69	Moderate	72
	Scientific language is used to explain the experiment	2.5	0.5	Good	83
Communicating approach of solution	Explain how the design solves the real-world demand or problem	2.83	0.37	Good	94
	Identify the organism's structure and function	2.83	0.37	Good	94
Improving the design	Explain the necessary improvement	2.5	0.5	Good	83
	Improve the design based on the information and evaluation acquired from the test and solution exchange	2.33	0.47	Moderate	78
		2.41	0.45	Moderate	80

Note. 1 - Low (1–1.49), 2 - Moderate (1.50–2.49), 3 - Good (2.50–3.00)

Each aspect of the evaluation results of the engineering design process is discussed below.

Identifying Demand or Problem

The average evaluation result for identifying the needs or problems was good ($\bar{X}$ = 2.83, SD = 0.37, 94%), and that for specifying the criteria and limitations was moderate ($\bar{X}$ = 1.83, SD = 0.37, 61%). Students could understand the problems encountered in daily life by clearly specifying needs or problems and presenting details to determine the scope of the problem before creating innovations or solutions. Students can also specify criteria and limitations, as shown in Table 3.

Table 3

Identifying demand or problem

Team	Identifying demand or problem	Criteria and limitation	Developing a possible solution
T5 Fish stool suction	Aquarium fish keepers normally find it difficult to clean moss and fish stool. The solution is to imitate a sucker catfish for fish stool suction.	Budget under 1,500 THB. The fish stool suction device needs to be moved manually, and thus, cleaning may take time.	Developed an innovative fish excrement vacuum cleaner that imitates the mouth of a sucker fish to solve the problem of large amounts of algae and fish excrement scattered in fish tanks.

Researching Demand or Problem

The average evaluation result for specifying necessary information to solve needs or problems was good ($\bar{X}$ = 2.67, SD = 0.47, 89%), and that for how to use the obtained information to solve human needs or problems was moderate ($\bar{X}$ = 2, SD = 0, 67%). Students could research and collect information related to a problem or need, find STEM ideas and knowledge from various sources, and clearly identify information necessary to solve problems or needs. In addition, they could determine how to collect the information required to solve needs or problems. For example, team T4 used knowledge about dragonflies (which inspired the solution), speed calculations, and drone technology as well as calculations of the area of the first aid equipment model for helping accident victims to control the drone in various simulated missions.

Developing a Possible Solution

The average evaluation result for proposing solutions to needs or problems was good ($\bar{X}$ = 2.67, SD = 0.47, 89%), and that for drafting blueprints of the solution was good ($\bar{X}$ = 2.5, SD = 0.5, 83%). Students could propose solutions to needs or problems according to the criteria and limitations by specifying existing limitations and criteria in the context of the problem, as in the example of team T3 (Table 3). Additionally, students could draft a detailed blueprint of the proposed solution.

Selecting Best Solution

The average evaluation result for considering the advantages and disadvantages of the proposed solutions was moderate ($\bar{X}$ = 2, SD = 0.82, 67%), and that for explaining the reasons (positive or negative, criteria, and limitations) for selecting the best solution was moderate ($\bar{X}$ = 2, SD = 0, 67%). Students could determine the pros and cons of most solutions and explain the rationale for the chosen solution, as seen in the example of team T3's selection of the best solution (Table 4).

Table 4

Selecting best solution

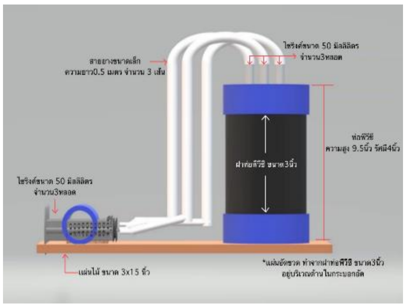
Team	Identifying demand or problem	Selecting Best Solution	Advantages	Disadvantages
T3 Automatic Trash Can – E.M. trash can	Exposure to trash while opening the trash can. Hand contaminated by germs.	Develop an automatic trash can that digests organic trash to minimize exposure to trash, reduce the risk of pathogens, and emulate nepenthes to trap and digest insects.	- A trash can opens and closes automatically to minimise exposure to trash and pathogens. - Organic trash can be used to produce biofermented water, which is useful for plants.	- Trash can does not open or close quickly because of the timing. - Speed of producing biofermented water depends on type and quality of organic trash. - Trash can uses a battery that needs frequent replacement.

Creating a Model

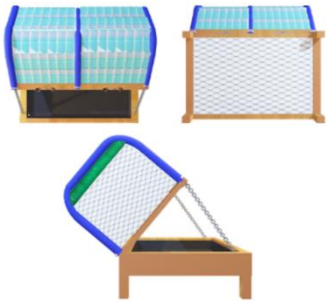
The average evaluation result for creating models or prototypes of solutions was good ($\bar{X}$ = 2.5, SD = 0.5, 83%), and that for using materials that meet the criteria and limitations of the model or prototype was moderate ($\bar{X}$ = 2.33, SD = 0.73, 78%). Most teams could create a fully suitable 3D model or 3D prototype for their solution by clearly specifying the dimensions of and materials used in the prototype while using materials that meet most of the model's criteria and constraints. Examples include team T1's prototype of a water-powered plastic bottle compressor that mimics the digestive system of a python and fluid energy transfer and team T6's water oxygenator for an aquarium that mimics a mudskipper (Figure 4). Team T2 developed a tree nursery with a structure based on mangrove tree roots and a roof imitating sea bass scales. However, they did not specify the size and materials used in the initial drawings. After expert feedback, they specified the size and type of materials used to build the tree nursery prototype to create a more complete and detailed model.

Figure 4

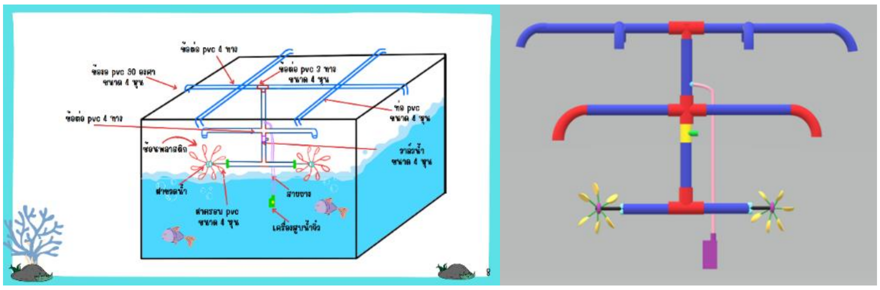
Sample of model or prototype of proposed solution



Team T1's prototype of a hydropower plastic bottle compressing machine emulating the digestive system of python and fluid energy transfer



Team T2's prototype of a plant nursery, where the structure imitates a mangrove root and the roof imitates a snapper's scale



Team T6's prototype of an oxygen pump for a fish tank that imitates a mudskipper

Testing and Evaluating Solution

The average evaluation result for testing how the model or prototype solves problems or needs was moderate ($\bar{X}$ = 2.17, SD = 0.69, 72%), and that for explaining test results using scientific language was good ($\bar{X}$ = 2.5, SD = 0.5, 83%). Once the prototype was complete, each team tested and evaluated the solution. Most teams tested the model for how it solves a need or problem and analysed only a portion of the test results. Students could explain the test results by using detailed scientific language. For example, team T1 studied the efficiency of bottle compression by comparing the change in shape of plastic bottles before and after compression and the time required by the machine to compress one bottle until its shape changes. They studied the number of plastic bottles that the machine can compress in 5 min, tested the efficiency of increasing the plastic bottle disposal space, recorded the results, and compared the storage volume before and after compression (Figure 5). Team members could explain and express their opinions by using scientific principles and concepts that were communicated to others to understand the test results correctly.

Figure 5

Team T1 's a test of compression efficiency and increasing plastic bottle dumping area

Communicating Approach of Solution

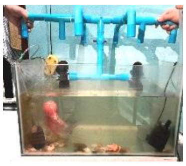
The average evaluation result for explaining how the design can solve human needs or problems was good ($\bar{X}$ = 2.83, SD = 0.37, 94%), and that for identifying the structures of living things and the functions of these structures used in design was moderate ($\bar{X}$ = 2.83, SD = 0.37, 94%). Students could clearly explain the design, including the structure of living things and its use as a model, and how it can solve human problems. For example, team T3 described the structure of the Nepenthes plant, consisting of the lid, peristome, wax zone, and digestive zone. This plant adjusts its leaves into colorful pot-like bulbs that attract and lure insects. The lid has nectar glands that attract insects. The inside of the pot is coated with wax so that insects fall into the pot, and the digestive juices produced by the plant digest the insects to obtain nutrients that the plant can absorb. The team imitated the adaptation mechanism of the Nepenthes plant to develop a biocomposting trash can whose lid closes and opens automatically using a sensor. In addition, EM microorganisms are used to increase the fermentation efficiency. This device produces nutrients for use as fertilizers.

Improving the Design

The average evaluation result for describing improvements needed for the design was good ($\bar{X}$ = 2.5, SD = 0.5, 83%), and that for improving the design based on test information and evaluation and exchanging solutions was moderate ($\bar{X}$ = 2.33, SD = 0.47, 78%). For example, team T6 identified the need to improve their design and then optimized the design based on the data, test results, and discussion of solutions (Table 5).

Table 5

Improvement of design

Team	Innovation	Improvement
T6 Oxygen pump in a fish tank		- Innovation from the PVC tube. Other types of tubes can be used to reduce the weight and accommodate movement. However, the strength will be compromised. - Six top beams adhering to the tank edge can be made adjustable for use with tanks of other sizes.

All 29 participants agreed that the PDP was beneficial in the creation of their STEM projects. Eight randomly selected participants were interviewed about the supporting factors and limitations of the program. They identified the following supporting factors: (1) technological adaptation skills to develop the model or prototype; (2) efficient communication skills and exchange of opinions; (3) teamwork skills to assist and brainstorm and to exchange knowledge about innovative designs; (4) good planning skills using the whole engineering design process; (5) key role of the advisor in successful innovation creation; (6) actual practice, pursuing knowledge, skills practice, self-learning to form knowledge, and knowledge propagation via the project; (7) understanding about STEM education projects based on knowledge of different fields; and (8) use of knowledge obtained from nature through observations and studies of organism structures and functions to determine the characteristics, qualities, and benefits, and observation of an organism with a similar problem that develops a structure and function to adjust itself to live in nature. The main limitations were the budget of the STEM education project, proficiency in each field, understanding of the engineering design process, and integration skills. All teams did not consider the inclusive integration of knowledge, and they required different knowledge fields to find the solution for a STEM project.

Discussion

The PDP successfully promoted STEM projects because biomimicry affords unique advantages that are suitable for interdisciplinary fields in STEM education. Natural processes can motivate a learner's imagination regardless of their age, interest, or cultural background (Pauls, 2017). The biomimicry approach adopted by scientists to realise innovative designs is incorporated into STEM education by using the biological theory obtained from observations of nature as well as mathematical and physical calculations as a foundation for the engineering design process. These were used to develop the required thinking and problem-solving skills and to create an understanding and awareness of natural resources in terms of their benefits to technology and innovation while being mindful of the importance of ecological balance (Putwattana, 2018). Biomimicry is a form of reversible engineering. The researcher identifies the problem, searches for biological sources to develop a natural solution to solve the problem, tries to understand the natural solution, and designs a solution for the benefit of humans (Gardner, 2012). Thus, the use of biomimicry in this study corresponds to the engineering design process based on STEM education guidelines.

Although students could successfully create biomimicry-based STEM projects by following the engineering design process, the results revealed some limitations. Students needed time to design and develop the innovation and learn about the difficulties during the design steps. Pongsophon et al. (2021) correspondingly found that science student teachers who joined a workshop to develop an understanding of the engineering design process learned about the design challenges. They had to consider the limitations during the design step. The innovator must work based on the prototype, test and improve it, and then create the final product. The design process was repeated, which was very complicated. Further, successes and failures allowed the learner to understand the biomimicry method (Qureshi, 2020). Further, the researchers found that students creating a biomimicry-based STEM project via the engineering design process had a moderate average score of 2.41, which accounts for 80% of the total possible score. In the problem identification step, most teams understood the problem and clearly stated it; however, they did not clearly state the criteria and limitations. The average score was not lower than those of other steps. Gencer et al. (2020) similarly reported that the scores of students in the problem identification step and the criteria and limitations identification step were lower than those in other steps. Further, the supportive factors for the success of the program were knowing that diverse technologies provide more choices, and innovations from the alternative subtechnologies can work together the best and can be extended (Prasertsan, 2015). Further, advisors, especially those who were enthusiastic and open-minded and sacrificed their time, played a crucial role in the success of STEM projects in Thailand. In addition, observations of the environment and surrounding nature can stimulate and initiate the concept of a solution. Close observations are likely to help construct the understanding of new concepts of nature (Chongsrid, 2016).

Conclusion and Implications

The PDP based on biomimicry was considered a success, and the researcher added a coaching strategy to support the programme by acting as a coach to advise students to exercise their and their team's potential via the practice and thinking processes to improve upon and develop their proposal constantly. They also meet a STEM expert to get feedback, which helped them to complete their quality innovation based on the prototype. The program participants can engage in the STEM project based on biomimicry by analysing a problem, obtaining data from nature, emulating, designing, exchanging, developing the prototype, testing, and evaluating. This process is reversible. The students can explain the structure and functions of the organism that inspired them to create the innovation and identify how it solves their problem. Moreover, they engage in the engineering design process and reflect on the STEM knowledge applied to the STEM project. Students also learn about the limitations and success during the program implementation.

Study Limitations and Recommendations

This study developed a PDP to improve STEM education projects and studied the implementation result of the programme with science student teachers in only one teacher training institute, which might not be adequate for interpretation or generalisation. The result is applicable to this study only. Although the program is successful, some student teachers do not have adequate knowledge about STEM education and misunderstand the emulation method, which is an obstacle to innovation creation via STEM projects. Therefore, further research may implement other development approaches, such as having professional mentors from various fields to accommodate the development of creative STEM projects.

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The effect of using a virtual anatomy system of student misconceptions on reproductive system

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ABSTRACT
This study aimed to determine the effect of using a virtual anatomy system (VAS) on student learning with regard to reproductive system with respect to the acquisition of misconceptions. This study used an experimental method by comparing the results of the class learning using virtual laboratory media with a control class. The result showed that a significant increase in learning outcomes in the experimental class 77.73 mean compared to the control class mean of 69.5. The magnitude of the increase in learning outcomes (N-gain) of the experimental class was 0.67 within the medium category beside control class. It can be seen that the level of misconceptions in the experimental class was 11.6% smaller than the control class at 37.6%.

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Introduction

Learning science will be more meaningful if it is accompanied by laboratory activities (Ping & Osman, 2019; Wiyanto et al., 2014). With laboratory activities, students' abilities in evaluating, designing, and processing problems increase (Bretz et al., 2013; Gutierez, 2015; Zeidler et al., 2019). Practical activities in the laboratory can train students' skills in scientific work (Wiyanto et al., 2014) and improve them mastery of concepts (Achuthan et al., 2020). The basic problem in schools is related to the use of laboratories in addition to limited facilities and infrastructure as well as limited human resources. Teachers as instructors need to understand and master laboratory equipment well. To overcome the lack knowledge science in higher education, it needs to be reorganized. Learning science in higher education requires the maturation of basic concepts as a basis for developing more complex concept. It needs to be supported by complete facilities and infrastructure such as a laboratory. The completeness of laboratory facilities and infrastructure affects students' skills.

One of the skills that a prospective science teacher must have is the ability to use laboratory equipment and materials effectively. Skills in laboratory utilisation and management support the science learning endeavour under Permendiknas 26 of 2008 regarding laboratory management in schools with certain qualifications for both laboratory heads and laboratory technicians (Manlea, 2017). Laboratory activities support the improvement of psychomotor competence and scientific attitudes as well as solve the problem (Talens, 2016). With laboratory activities, student activities increase up to 80% in the learning process (Yusuf & Subaer, 2013). laboratory activities increase students' understanding of the material that is being studied (Ratamun & Osman, 2018) not only theoretical and abstract. A virtual laboratory is an interactive environment for creating and conducting experiments that is adapted to simulate processes and actions as in a physical laboratory. Or in other words, virtual laboratories are an affordable way for schools or universities to get laboratories for all kinds of subjects. Teachers use sophisticated technology to present a series of experimental processes that will produce authentic results. Virtual laboratories use the computer to simulate complicated things, expensive experiment devices, or replace the experiments located in hazardous environments (Mahanta & Kumar Sarma, 2012) Virtual laboratories become an option considering that currently there has been such rapid progress in information and technology (Zaturrahmi et al., 2020).

Compared to physical laboratories which obviously have limited space, virtual laboratories can be used to demonstrate the latest technologies in all classes. Virtual laboratories as complementary or independent facilities. Virtual laboratories can be a standalone activity when physical laboratories are unable to facilitate experiments due to limited resources. Virtual laboratories are even more efficient, significant and affordable for educational institutions in developing countries (Widiyatmoko et al., 2022), because the facilities available in physical laboratories are sometimes still scarce. Even though many have physical laboratories, the existing facilities are not yet complete so the learning potential is less than optimal. Learning using virtual media has the potential to make students active in learning because there are activities that may not be able to be fulfilled in a physical laboratory (Tuysuz, 2010).

Understanding science concepts is an important indicator for achieving success in science learning. Understanding concepts in science learning takes the form of mastering concepts that are in accordance with the agreement of scientists, do not deviate and do not give rise to other hypotheses that can cause cognitive conflict. Meanwhile, misconceptions are errors or discrepancies between concepts and scientific understanding accepted by experts. Misconceptions can also occur in students from students themselves, teachers, textbooks, and also from the learning methods carried out by student. Misconceptions can take the form of errors in understanding the initial concept, errors in connecting various concepts, and errors in ideas. Misconceptions can easily occur to students when students are trying to form knowledge based on new experiences (Hakim et al., 2012; Mufit et al., 2023).

Learning using virtual laboratory can support teachers in providing understanding to students (Resbiantoro et al., 2022; Rowe et al., 2018; Winarni, 2020). However, the limitations in the availability of facilities, and infrastructure (Alneyadi, 2019; Faour et al., 2018; Ratamun & Osman, 2018) as well as limited human resources make teaching science based on laboratory activities a challenge in itself. The development of learning using virtual laboratories has been widely developed, especially in higher education environments, to accommodate the limitations of physical laboratories.

This limited infrastructure problem can be overcome by using virtual technology that is designed according to the user's needs (Faour et al., 2018). The use of computers in developing virtual media in education is growing rapidly (Gunes et al., 2015; Thohir et al., 2020; Widiyatmoko, 2018).

This developing technology can provide practical solutions for science teachers to improve student learning outcomes despite limited facilities and infrastructure. Virtual laboratories provide opportunities for students to learn through joint activities in processing information, changing variables (Faour et al., 2018; Rowe et al., 2018), and seeing the impacts of the activities' results (Pujiastuti & Haryadi, 2020; Yuniarti et al., 2012). Learning using virtual tools can make students more active in learning and processing information (Gunawan et al., 2017; Ratamun & Osman, 2018). A facility that combines technological advances with limited laboratory activities means such as the *virtual anatomy system (VAS)*.

Virtual laboratories are used as supporting tools to enrich real experiences and motivate (Achuthan et al., 2020) students to conduct experiments and develop experimental skills. Through the use of virtual laboratory media for students of prospective teachers, it is hoped that the learning activities will be more meaningful with students identifying and practicing virtually.

A virtual anatomy system (VAS), which required experimentation or practicum to help explain the concepts in anatomy material, could be used as an alternative learning activity. The research conducted has also been investigated by Jaya in vocational education for Vocational High School (SMK) students. He stated that the development of a virtual laboratory for practicum activities can increase motivation which has an impact on increasing their cognitive abilities as well as improvements that lead to the psychomotor aspects and character of vocational high school students (Jaya, 2012). Virtual laboratories have advantages in improving students' affective abilities that describe feelings, interests, and attitudes towards the teaching process (Achuthan et al., 2020; Purwati et al., 2019). Research conducted by Isdaryanti related to the teaching aspect, it was known that when the performance ability of science teachers in teaching increases, then it has an impact on improving the student's character education (Isdaryanti et al., 2018). Therefore, increasing the ability to teach concepts to students of prospective teachers must be implemented (Winarni, 2017) as much as possible.

Several advantages can be obtained by having a virtual laboratory, including (1) because it does not require tools and materials like conventional laboratories so it is more economical (Fonna et al., 2013; Winarni, 2020), (2) it increases student motivation and curiosity, (3) it increases the students' ability to solve problems in learning (Anisa et al., 2020; Jannati et al., 2019; Winarni, 2020). Students can also do experiments wherever and whenever they need it. In addition, students can also try to repeat the material and study materials related to experiments. Another advantage of virtual laboratories is that they can train students' accuracy in developing concepts found from the results of practicum activities even though in the conditions with limited facilities such as tools and practicum materials.

Many developments in virtual media have been carried out and show that the use of virtual media, apart from improving student learning outcomes, also has an impact on increasing student motivation (Said, 2014) and increasing students' analytical skills (Widiyatmoko & Shimizu, 2019; Winarni, 2020). This study aims to determine the effect of use of the virtual anatomy system (VAS) of students' misconceptions on reproductive system.

Methods

Design Development

This research used a quasi-experimental method (Hastjarjo, 2019) by comparing the control group and the experimental group. Learning that uses a problem-based approach, for example in the female reproductive system, is how the female sex cells look ready to be fertilized during the mating season. In the experimental group, learning was supplemented by using virtual practicum with VAS, while the control group was not provided with additional practicum using VAS.

The samples for this research were 11 students in the experimental class and 10 students in the control class. In the experimental activity class, students are given material at the first meeting. At the second meeting, students were given an explanation of the phases of egg cell development and carried out practical activities using a VAS until the focus was found from the virtual observation. The results obtained are described and analyzed including the egg cell development phase. For the control class, at the first meeting, material was provided. At the second meeting on egg cell development, students were asked to look for references to strengthen the explanation of the phases of egg cell development. After the second meeting ended, reflection and testing was carried out to see the level of understanding and whether there were any misconceptions that occurred after the learning was carried out.

Data Collection

Research data is in the form of test results arising from multiple choice objective tests supplemented by the Certainty Response Index (CRI) method for students (Hasan et al., 1999; Mustaqim et al., 2014). Table 1 CRI categories and category explanations.

Table 1

Cri scale by Saleem Hasan

Scale	Category
0	(Totally guessed answer), if the answer to the question is 100% guessed
1	(Almost guess), if you answer the question, the percentage of guess elements is between 75% -99%
2	(Not sure), if you answer the question, the percentage of guess elements is between 50%-74%
3	(Sure), if you answer the question, the percentage of guess elements is between 25%-49%
4	(Almost certain) if you answer the question, the percentage of guess elements is between 1%-24%
5	(Certain,) if you answer the question, there is no element of guessing at all (0%)

Results and Discussion

Research was carried out to determine the effectiveness of learning using VAS to overcome misconceptions. The results acquired showed that there was a significant difference between the experimental learning method using VAS on the reproductive system compared to the control class. The results of this research are in line with research conducted by Gunawan regarding the use of virtual labs in learning which was able to improve problem solving abilities in the experimental group compared to the control group (Gunawan & Liliasari, 2012).

The data obtained from the results of the recapitulation of students' pretest and posttest can be seen in Table 2. The results of student scores analysis.

Table 2

Data on comparison of learning outcomes for experimental and control groups

	Experiment class			Control class		
	pretest	*Posttest*	*N-gain*	*Pretest*	*postest*	*N-gain*
N (Number of students)	11	11		10	10	
Average	31.82	77.73	0.67	32.5	69.5	0.55

Table 2 shows that the mean score of the experimental group pretest is 31.82 and posttest is 77.73 with an N-gain reaching 0.67 which is in the medium category, while in the control group, the pretest score is 32.5 and the post-test score is 72.5 with an N-gain of 0.59 which is included in the medium category.

Table 3

T-test to see the significance of student learning outcomes

	F	Sig.	t	Df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence Interval of the difference	
								Lower	Upper
Score equal variances assumed	3,79	.066	-3,91	19	.001	-8.22727	2.10426	-12.631	-3.823
Score equal variances not assumed			-3,98	17,35	.001	-8.22727	2.10426	-12.571	-3.882

The results of the calculation of the significant value of 0.001 <0.005, it can be concluded that there is a difference between the learning outcomes of the experimental group and the control group

From the calculation of the N-Gain data, it can be seen that there was an increase in understanding of the concept received by the experimental group compared to the control group. So learning using the virtual anatomy system (VAS) as a learning medium helped to clarify the concept of the reproductive system for prospective teachers. The use of virtual laboratories also resulted in higher N-Gain in the experimental group compared to the control group in other research with different concepts (Athaillah et al., 2017). The results of research on learning with virtual media are in line with research conducted by Swandi (Swandi et al., 2015) in adding virtual media to modern physics learning using virtual laboratories which can improve generic science skills. Based on increased thinking abilities or learning outcomes, it can be used as a basis for learning outcomes data that can also have an impact on the possibility of reducing misconceptions.

Research on virtual media in learning anatomical concepts was also carried out by Fonna (Fonna et al., 2013) on the respiratory system, the results showed that the critical thinking skills of the number of students in the experimental group who used the virtual laboratory were better than those in the control group who did not use the virtual laboratory. Research relating to virtual media has shown significant results. Therefore, in research using VAS in learning the reproductive system is effective in preventing misconceptions.

This virtual anatomy system (VAS) media is realistic because it is very complete and contains materials and tools to be used in laboratory activities. The use of a virtual laboratory on reproductive material could facilitate students to understand the processes that occur in the reproductive system, starting from the process of observing the morphology of sperm cells, counting the number of spermatozoa, and observing egg cells according to the stage.

Errors made in laboratory activities using a virtual anatomy system (VAS) will train students as practical activities in the laboratory directly. This means that when students are faced with real conditions in the laboratory, errors in practical activities can be overcome. The use of the virtual anatomy system (VAS) on the reproductive system has had a positive impact on students so it will be told for the umpteenth time. This is shown in the student response questionnaire, the results of which are shown in table 4 below.

Table 4

Description of student responses

No.	Indicator	Statement	Agree	Disagree
1	Laboratory virtual views	Display under actual laboratory conditions	81.8%	18.2%
		Virtual Laboratory Stages is easy to use	72.7%	27.3%
		The virtual lab is very interesting to use	81.8%	18.2%
2	Media conformity to the concept	Using virtual laboratory media makes it easier to understand the concept of learning	72.7%	27.3%
		Virtual laboratories are very useful in the learning process	72.7%	27.3%
		The virtual laboratory makes it easy for me to do practical activities virtually	72.7%	27.3%
3	Virtual lab performance	Easy to access virtual lab	81.8%	18.2%
		Virtual lab saves time and money	72.7%	27.3%
		The virtual laboratory can be relearned after learning activities	72.7%	27.3%
		I wish there was a virtual lab for other materials	81.8%	18.2%
Average			76.3%	23.7%

The results of student responses to the appearance, the suitability of the media with the concept, and the performance of the virtual laboratory showed that 76.3% of students agreed that the virtual laboratory that was made and used was attractive, appropriate, and increased the desire to learn and the desire for similar learning media. This interest makes students better understand the material presented by the lecturer as a form of increasing curiosity (Tuysuz, 2010). With the virtual anatomy system (VAS), students were able to re-access practicum activities carried out to solidify the concepts (Rohmawati et al., 2018) that were learned so that learning activities became more effective and efficient. This positive student response makes the virtual anatomy system (VAS) a medium that needs to be developed more to improve the quality of learning in the future.

Conclusion

The conclusion and implication of this research is that understanding concepts is helped by using virtual anatomy system (VAS) media on reproductive system material. The average value of learning outcomes and understanding of concepts for experimental group students was better in understanding concepts than those in the control class. This improvement in learning outcomes is supported by positive student responses that support the use and development of the virtual anatomy system (VAS) to the next stage.

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Moroccan high school science teachers' self-efficacy beliefs in the context of French medium instruction

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ABSTRACT
The relationship between science teachers' self-efficacy and the language of instruction is a critically under-research issue in education. This study aimed to explore public school science teachers' self-efficacy with regard to the use of the language of instruction in teaching scientific subjects. Specifically, the present paper attempts to uncover the impact of the recent French medium instruction (FMI) policy on Moroccan teachers' sense of self-efficacy for teaching science and to examine how demographic variables (age, gender, education and teaching experience) modify or change self-efficacy beliefs. To that end, 151 in-service high school science teachers completed a short self-efficacy Likert scale designed especially for the purposes of the study. The results showed that science teachers have low self-efficacy beliefs with regard to the use of French as a medium of instruction (MoI). Also, while age and teaching experience were found to have a statistically significant correlation with self-efficacy, teachers' language proficiency did not. The study concludes that MoI can negatively impact teachers' self-efficacy and that the latter becomes stronger with age and accumulated experience. Moreover, having teachers with good language proficiency does not guarantee high self-efficacy beliefs. The study discusses some implications of these results for educators and educational policymakers.

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Introduction

Self-efficacy is one of the key constructs of psychology. It basically refers to a person's beliefs in her or his own perceived capabilities to manage and perform a particular task. It was first used by Albert Bandura (1977) in his seminal work '*Self-efficacy: toward a unifying theory of behavioural change*'. According to Bandura's theory, self-efficacy has a far-reaching impact on individuals' thought and behaviour. People with a high sense of self-efficacy are believed to be resilient in the face of obstacles while those with a low level of self-efficacy usually do not show perseverance in pursuing their goals. Given its importance, the construct is widely researched in the field of education. Educational effectiveness has been consistently associated with students' and educators' self-efficacy beliefs. This way, an increased sense of self-efficacy in teachers and students has been seen as facilitating the improvement of educational outcomes.

Teachers' self-efficacy, in particular, has been the focus of a large body of research. According to Tschannen-Moran & Hoy (2006), teacher self-efficacy is 'a little idea with big impact' (p.954). With this presumed impact' in mind, empirical educational research has applied Bandura's theory to uncover the practical effects and major predictors of teacher self-efficacy. Thus, teachers' self-efficacy beliefs have been studied in relation to science (e.g., Azar, 2010) the use of technology (e.g., Abbitt, 2011; Holden & Rada, 2011) language proficiency (e.g., Chacón, 2005) inclusive education (e.g., Malinen et al., 2012) and many other aspects of teaching. Although various studies have focused on science teachers' self-efficacy, they have failed to throw light on the intricate relationship between science teachers' self-efficacy and the medium of instruction used to teach science subjects, especially in multilingual contexts. Very few studies have dealt with this neglected issue (see related works section below) and in the Moroccan context, research on self-efficacy in the domain of education is rare (we could identify only two studies: (Hassan & Ibourk, 2021; Laouni, 2023). The present study seeks to narrow this gap in research about science teachers' self-efficacy in the context of the language of instruction.

In 2019, the Moroccan Ministry of Education introduced a new language policy known as the Language Alternation Policy (LAP). The use of French as a medium of instruction (FMI) in teaching science subjects was one of the main ordinances of this policy. The policy was part of a larger reform of the education system in the country. One major justification for the new policy was the claim that the Arabisation policy, especially the teaching of scientific disciplines in Arabic, had failed. However, the introduction of the policy was not preceded by any evaluation of teachers' and pupils' readiness to adopt the French language as a medium for teaching science. Given the fact that these teachers have been teaching in Arabic for years, the new policy was expected to create challenges for teachers and impact their sense of self-efficacy.

Taking a quantitative approach to this problem, this study, thus, aims to reveal Moroccan secondary school science teachers' self-efficacy beliefs for the use of French medium instruction to teach science subjects. It attempts to show the impact of the new policy on science teachers' perceived self-efficacy and examine how the latter interacts with a number of other factors.

Theoretical Framework

Bandura's Social Cognitive Theory

The concept of *self-efficacy* was developed by Albert Bandura as part of his Social Cognitive Theory. In his 1997 book, *'Self-efficacy: The exercise of control'*, Bandura defines perceived self-efficacy as ''beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments'' (p. 3). Defined this way, self-efficacy is seen to exert a significant influence on human agency. Supposedly, it shapes individuals' thought, motivation and behaviour. How a person perceives their self-efficacy determines the amount of effort they invest in pursuing courses of action and their resilience in the face of obstacles (Bandura & Adams, 1977).

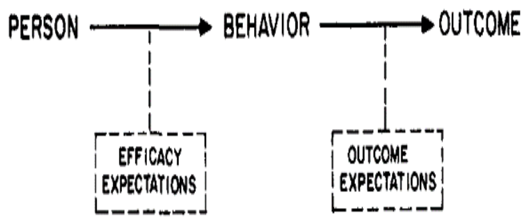
According to Bandura (e.g., 1977, 1997, 1995) people process and integrate self-efficacy information from four main sources. First, there are enactive mastery experiences. These are successful experiences that confirm one's capability. The second source is vicarious experiences which involve information gained from observing and comparing one's competencies with other individuals. The third source is verbal persuasion which involves the influence of others who convince one of possessing particular abilities. The last source is physiological and affective states which comprise a range of psycho-somatic experiences. These can 'partly' influence one's judgment of their capabilities.

In Bandura's model, the distinction is drawn between two types of efficacies, namely *perceived self-efficacy* and *outcome expectancy*. While perceived self-efficacy is the sum of efficacy expectations, that is, someone's belief in their competence to perform a given task, outcome expectancy is a 'person's estimate that a given behaviour will lead to certain outcomes' (Bandura, 1977, p. 193). In other words, when interested in perceived -self-efficacy one asks, 'Do I have the ability to organise and execute the actions necessary to accomplish a specific task at a desired level?' and to evaluate the outcome expectancy one would ask, 'If I accomplish the task at that level, what are the likely consequences?'(Tschannen-Moran, Hoy, et al., 1998). Figure **(1)** below shows the difference between the two types of self-efficacy. Figure (2) shows a reworked model that depicts self-efficacy in a MoI situation where the language of instruction *mediates* perceived self-efficacy and outcome expectancy.

Although it demystified the ambiguous nature of the psychological construct of self-efficacy and showed its strong impact on peoples' agency, Bandura's theory of self-efficacy has been subject to some criticisms. Researchers pointed out its theoretical and methodological limitations (Eastman & Marzillier, 1984) such as its emphasis on the linear correlation between efficacy and performance (Yeo & Neal, 2013), overlooking idiosyncratic differences between individuals, and downplaying the role of contextual and cultural factors (Pajares, 1997). The theory, however, remains robust and widely influential as it offers a powerful explanatory framework and its principle theoretical tenets have been tested and retested in empirical research.

Figure 1

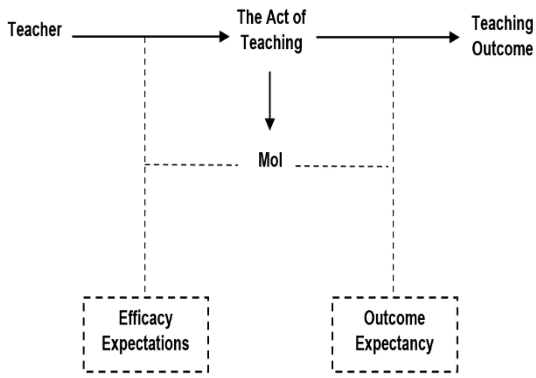
Diagrammatic representation of the difference between efficacy expectations and outcome expectations.



Note. Adopted from Bandura's (1977), 'Self-efficacy: Toward a Unifying Theory of Behavioural Change', p.193.

Figure 2

A reworked model where medium of instruction mediates efficacy expectations and outcome expectations.



Teacher Self-Efficacy Beliefs

According to Tschannen-Moran & Hoy (2001), teacher efficacy is a 'simple idea with significant implications' (p. 783). Indeed, these 'implications' are very important and relevant to education. They mainly relate to teachers themselves and to a greater degree to their pupils. As for teachers, it frames their experiences in the classroom and interferes with their professional development. Concerning pupils, teacher self-efficacy is claimed to directly affect learning outcomes (Blonder et al., 2014). Old and recent studies show that a teacher with a high level of self-efficacy beliefs is alleged to positively affect learners' sense of accomplishment and boost their motivation and their own sense of self-efficacy (e.g., Ross, 1992; Mojavezi & Tamiz, 2012; Taştan et al., 2018). Teachers with a strong sense of self-efficacy tend to set ambitious yet measurable goals and invest their effort accordingly (Pajares, 1992, p. 310). Concerning teaching efficacy, teacher self-efficacy has been defined as a teacher's 'judgment of his or her capabilities to bring about desired outcomes of student engagement and learning, even among those students who may be difficult or unmotivated' (Tschannen-Moran & Hoy, 2001, p. 783). It is, thus, viewed as being a personal belief in one's teaching abilities to effectively conquer teaching tasks and bring about desired change in learners.

Teacher self-efficacy is a slippery concept that is embedded in a complex belief system and its measurement poses problems for researchers. However, given its presumed effect on the improvement of educational outcomes, researchers developed several scales to 'measure' teacher self-efficacy. In this respect, Tschannen-Moran & Hoy (2001) delineated two major strands in the measurement of teacher self-efficacy. The first strand incorporated Rotter's social learning theory, while the second was inspired by Bandura's social cognitive theory. Researchers from both schools have developed several teacher self-efficacy scales with different purposes and foci. Pajares (1997) notes that teacher efficacy is a key construct in teacher education and calls for more research on how it develops and the factors that influence it. In the present paper, we attempt to throw some light on instructional language, a hitherto ignored factor which mediates science teachers' self-efficacy and the outcomes of the teaching-learning process.

Related Works

Medium of Instruction and Science Teaching

Language is of extreme importance in the science classroom. Vygotsky (2012) noted that "children solve practical tasks with the help of their speech as well as their eyes and hands" (p.26). Indeed, this is usually the case in the science classroom where not only pupils but also their teachers get tasks done through and with the help of language. As such, language assumes a decisive role in the learning process, in that, it functions as the medium through which the teaching and learning of science occurs (Wellington & Ireson, 2012). It can considerably determine what learners comprehend and, ultimately, what they can do with their acquired scientific knowledge. Also, language can be used as a tool for knowledge generation in science classrooms (Si et al., 2024). However, despite the asserted role of instructional language in the teaching of science, teachers are reported to overlook its importance. For instance, Tan (2011) found that content-oriented teachers believed that that language was just a 'vehicle' for content transmission, overlooking its essential role in constructing meaning and subject-specific discourse.

In fact, being the main channel through which scientific knowledge is transmitted, any language used as a MoI can become a major barrier to the teaching-learning process, especially when this is not the teachers' and the students' native language. Research shows that science teachers believe that the language of instruction (e.g., English) can be a major barrier to acquiring scientific knowledge (Seah, 2016) as it can prevent the full comprehension of science concepts and, consequently, negatively affects learners' sense of competence and self-esteem (Mthiyane, 2016). According to Motloung et al. (2021), both experienced and novice teachers share the view that the use of L2 (English) as a medium is a real 'barrier' to the teaching and learning of life sciences. Additionally, the use of L2 as MoI usually brings to the fore several challenges mainly teachers' and learners' low proficiency, the unclarity of top-down MoI policy and the absence of support and incentives (Lourenço & Pinto, 2019). In response to these challenges faced by science teachers in L2-mediated science classrooms, teachers more often than not engage in several cross-linguistic practices as coping strategies. Code-switching, for instance, is a preferred teaching strategy that science teachers adopt to ensure science concepts are understood by their pupils (Motloung et al. 2021). Also, translanguaging is widely practised in science teaching, especially in multilingual classrooms (e.g., Charamba, 2020; Karlsson et al., 2019; Lemmi & Pérez, 2024). According to García & Wei (2014), translanguaging is "an approach to the use of language, bilingualism and the education of bilinguals that considers the language practices of bilinguals not as *two autonomous* language systems as has been traditionally the case, but as *one linguistic repertoire*" [emphasis added] (p. 2). Unlike code-switching in which bilingual speakers switch between languages or grammars, translanguaging refers to language practices which draw on the full linguistic repertoire of bilinguals.

While, to the best of our knowledge, there are no studies that explicitly explore the direct relationship between the use of a particular language for instruction and science teachers' self-efficacy, we presume that the challenges accompanying the use of L2 as a MoI do impact science teachers' sense of self-efficacy, especially when these teachers face problems of proficiency in a multilingual context as that of Morocco. Elsewhere, it has been found that science teachers face enormous challenges primarily due to a lack of proficiency in the MoI (Al Zumor, 2019; Pun et al., 2024), which influences their classroom leadership (Wang, 2023). These studies imply that the ignored variable of language of instruction in science classrooms, particularly the use of L2, does influence teachers' sense of self-efficacy. The next section reviews research that touched on this issue.

Science Teachers' Self-Efficacy Beliefs and MoI

We venture to claim that the nexus between science teachers' self-efficacy and the medium of instruction is a huge gap in the literature. Our search for the terms 'teacher AND self-efficacy AND language/medium of instruction' and their different combinations on Google Scholar, Scopus and Web of Science databases yielded very limited results (4 moderately relevant studies). Unlike language teachers' self-efficacy which received a good deal of attention, science teachers' self-efficacy beliefs regarding the use of instructional language in the science classroom remain under-researched. A lot of research studied science teachers' self-efficacy beliefs but failed to connect it to an extremely important variable which is the medium of instruction, especially in multilingual classrooms. In this section, we discuss exclusively the studies that looked at the issue of the language of instruction in relation to teacher self-efficacy in MoI contexts in general and in science classrooms in particular.

Research exploring the interconnection between teachers' self-efficacy and MoI has been mostly conducted in English medium instruction (EMI) contexts. The studies by Shanahan & Shea (2012), Chen & Peng (2019) and Tsui (2018) explored the impact of professional programmes on EMI teachers' sense of self-efficacy. Shanahan & Shea (2012) investigated the results of a PD model which integrated the science inquiry approach with language learning. The study found that there was an improvement in the participating teachers' self-efficacy about language instruction and in their confidence in integrating science and language teaching. Similarly, using Bandura's theory of self-efficacy as a theoretical framework, Tsui (2018) studied the impact of an EMI teacher PD on Taiwanese university teachers. The study reported that although novice EMI teachers initially showed low self-efficacy beliefs, there was a positive shift in their self-efficacy by the end of the programme. In China, Chen & Peng (2018) also noticed that EMI teachers' sense of self-efficacy had improved as they became more aware of the nature and role of language in content teaching after attending a PD programme.

Language attitudes and language proficiency are two variables that were also found to interact with teachers' self-efficacy. For instance, Goh & Luen Loy (2021) investigated the connection between self-efficacy and Malaysian preschool educators' attitudes to the English language as a medium of instruction (EMI). They found that teachers with a strong sense of self-efficacy were more prone to use English for teaching. More importantly, the study found a strong correlation between self-efficacy and attitudes toward language. Wang (2021) explored the nexus between EMI teachers' self-efficacy beliefs and their classroom language proficiency. He found that language proficiency strongly correlated with teaching self-efficacy. Language of instruction and language of interaction, in particular, had a higher correlation with EMI teachers' self-efficacy.

In all, the above studies underscore the intricate relationship between teachers' self-efficacy and MoI. They demonstrate the favourable influence of professional development (PD) programs addressing MoI-related matters on teachers' self-efficacy beliefs while also emphasising the robust correlation between language proficiency, language attitudes, and teachers' self-efficacy.

Research Objectives and Questions

Given that the purpose of the study was to assess science teachers' personal self-efficacy beliefs (not outcome expectancy) for the use of French in as MoI, the present study has the following objectives:

- Assess Moroccan high school science teachers' self-efficacy beliefs with regard to the use of French as MoI for science subjects.
- Test the correlations between demographic variables (age, gender, educational background and speciality) and teachers' self-efficacy beliefs for FMI.
- Explore the relationship between their self-efficacy for FMI and language proficiency.

Based on these stated objectives, the present study is guided by the following questions:

- What are Moroccan high school science teachers' self-efficacy beliefs regarding the use of French as a medium of instruction?
- What is the impact of demographic variables on their self-efficacy beliefs?
- Is there a difference in self-efficacy beliefs for the use of French as MoI in Maths and Life and Earth Sciences (LES) teachers?
- Is there a correlation between language proficiency and science teachers' self-efficacy for the use of French as MoI?

Methodology

Assessing Science Teachers' Self-Efficacy Beliefs for FMI

Participants

The Moroccan in-service high school science teachers (n = 151) who participated in the present study all belonged to the public school system. The sample comprised Life and Earth Sciences (n = 93) and Mathematics (n = 58) teachers. They were randomly selected from all over the country. An online version of the questionnaire was hosted on Google Forms and a link was shared with these teachers via email and social media platforms. Participants were instructed to complete the questionnaire at their convenience, and anonymity and confidentiality were ensured throughout the data collection process. All participants were informed about the purpose of the study and participated voluntarily. Table (1) below shows the main characteristics of the sample:

Table 1

Demographic characteristics of study participants

	Category	%	Count
Gender	Female	51%	77
	Male	49%	74
Age	<= 29	38%	59
	30 - 39	20%	31
	40 - 49	26%	40
	50 - 59	10%	15
	60+	4%	6
Highest qualification	BA	53%	80
	MA	42%	65
	PhD	4%	6
Specialty	LES	71%	108
	Maths	28%	43

Experience	1-5 yrs	34%	52
	5-10 yrs	20%	31
	10-15 yrs	20	31
	15-20 yrs	2%	3
	20+ yrs	22%	34

Research Instruments

Scale Development: A self-report scale was used in the present study. The instrument was developed based on extant science teachers' self-efficacy beliefs scales and a review of the literature about teacher beliefs, teacher self-efficacy, and language-in-education policy, particularly MoI policy. Extant self-efficacy scales consulted are Bandura's (1977) Teacher Self-Efficacy Scale (TSES), Science Teaching Efficacy Belief or STEBI (Riggs & Enochs, 1990) and Teachers' Sense of Efficacy Scale or TSoES (Tschannen-Moran & Hoy, 2001). These are established scales with demonstrated reliability and validity in similar contexts (see Tschannen-Moran & Hoy, 2001).

Our scale consisted of an introductory section about demographics and three main subscales, namely *efficacy in student engagement* (items 1-3), *efficacy in instructional strategies* (items 4-9) and *efficacy in classroom management* (items 10-11). The validity of these subscales (as a general scale structure) was established by a factor analysis that consistently showed the existence of a moderate correlation between the three factors (Tschannen-Moran & Hoy, 2001). This established factor structure served as a guide for the inclusion and organisation of the adapted and self-generated items in our short scale to ensure content validity. The 11 items were measured on a 5-point Likert scale ranging from strongly agree = 5 to strongly disagree = 1 (see Table 3). Items adapted from other teacher self-efficacy scales were reformulated to suit the specific requirements and nuances of the present study, chiefly the integration of FMI as a main concern (see Table 4). Table 2 shows the source of the included items and their contribution to the overall reliability of the scale. Given the small number of items (11), the decision was not to conduct a new factor analysis as the dataset may not provide enough information to reliably extract meaningful factors. Accordingly, we opted for reliability testing to assess the internal consistency of the scale (see next section).

Table 2

The source of scale items with their contribution to the overall reliability

Item	Source	Contribution to the Overall Reliability
1	Self-generated (based on the literature about the relationship between attention and student engagement)	0.803
2	TSoES (adapted from item 4)	0.804
3	TSoES (adapted from item 12)	0.786
4	TSoES (adapted from item 10)	0.802
5	TSoES (adapted from item 11)	0.804
6	TSoES (adapted from item 17)	0.794
7	- TSoES (adapted from item 20) - STEBI (adapted from item 22)	0.811
8	Self-generated	0.789
9	Self-generated (based on empirical studies about MoI (e.g., Pun et al., 2022)	0.798
10	- TSoES (adapted from item 3) - TSES (adapted from item 14)	0.811
11	Self-generated	0.815

Scale Reliability*:* To assess the internal consistency and reliability of the self-efficacy scale used in the present study, Cronbach's alpha was calculated. The obtained Cronbach's alpha value was α = 0.81, indicating high internal consistency and, therefore, suggests that the scale is a reliable instrument for measuring self-efficacy levels in the target population. Moreover, all the items included positively correlated with each other, however, the correlation remains generally moderate and some of the items show weak correlations as shown in table 3.

Table 3

Inter-item correlation matrix

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11
Item 1	1,000										
Item 2	,415	1,000									
Item 3	,543	,511	1,000								
Item 4	,392	,447	,423	1,000							
Item 5	,287	,063	,336	,319	1,000						
Item 6	,416	,457	,380	,547	,186	1,000					
Item 7	,211	,092	,321	,014	,343	,308	1,000				
Item 8	,280	,539	,506	,164	,262	,459	,432	1,000			
Item 9	,346	,295	,348	,335	,411	,189	,426	,385	1,000		
Item 10	,107	,073	,364	,118	,242	,287	,326	,426	,085	1,000	
Item 11	,079	,058	,254	,365	,296	,151	,038	,193	,348	,231	1,000

Data Analysis Procedures

SPSS v. 25.0 (IBM Corp, 2017) was used for the statistical analysis of the obtained data. Given the controversy surrounding the analysis of Likert scales and the fact that our dataset shows breaches of normality assumptions, we opted for frequency, mode and median as preferred statistics to describe our data as this, we believe, will make more sense of the obtained results, especially since the negatively worded items are not reverse coded yet. Later on, negatively worded items were reverse-coded in such a way that a higher score corresponds to a higher sense of self-efficacy for the use of FMI. At this stage, parametric tests were used to check for correlations and to calculate the mean difference between subgroups within the sample. The justification for the use of parametric tests at a later stage in the analysis is that the distribution of average scores (used as the dependent variable in these tests) of the summated scale relatively meet the assumptions of normality (e.g., Carifio & Perla, 2008) and, thus, we believe the results obtained are statically valid. We use Pearson correlation coefficient (r) to check for correlations between science teachers' self-efficacy beliefs regarding the use of French as MoI and other variables of interest such as age, gender, educational background and speciality, while Independent Samples t -Test was used to compare mean differences between Life and Earth Sciences and Maths teachers.

Findings

As abovementioned, the scale consists of three subscales and 11 items (Table 4). The composite score is (55), that is, a high score means that teachers have a high level of self-efficacy for using French as MoI to teach science subjects, whereas a low score means their sense of self-efficacy beliefs for the FMI is low. The minimum score was 12 and the maximum was 40. The median was 23 and the mode was 25.

Table 4

Descriptive statistics for the scale items

	Items	Median	Mode
1.	I believe that when I use French a large number of pupils lose attention	5,00	5
2.	I believe that when I use French 'weak' pupils lose interest in my lessons	5,00	5
3.	I believe that French limits students' creativity in science classes	4,00	5
4.	I believe that the French language makes it difficult for me to gauge pupils' comprehension	4,00	5
5.	I believe that the French language makes it difficult for me to craft good and comprehensible questions for my pupils	3,00	3
6.	I believe that the French language makes it difficult for me to adjust my lessons to the proper level of individual learners	4,00	4
7.	I believe that the French language makes it difficult for me to provide an alternative explanation when learners are confused	4,00	5
8.	I believe that the FMI policy makes my teaching of science less effective	4,00	5
9.	I believe that the FMI policy limits classroom interaction and therefore obstructs knowledge construction	4,00	4
10.	I believe that the French language makes it difficult for me to deal with disruptive behaviour	3,00	2
11.	I believe that the FMI policy makes it difficult to manage class time effectively	4,00	4

Item-by-Item Analysis

Efficacy in Students' Engagement

Item 1: *'I believe that when I use French a large number of pupils lose attention.'* The participants' median response to this statement is 5, which is the highest possible rating on the scale. Additionally, the mode is also 5, indicating that the most common response is the highest rating. This suggests that a significant proportion of participants strongly agree that using French leads to a large number of students losing attention in the classroom.

Item 2: *'I believe that when I use French 'weak' pupils lose interest in my lessons.'* Similar to Item 1, participants' median and mode responses for this statement are 5, indicating a strong agreement with the idea that 'weak' students become disinterested when French is used in lessons. This suggests that participants perceive French as potentially hindering the engagement of struggling students.
Item 3: 'I believe that French limits pupils' creativity in science classes.' The median response of 4 indicates that, on average, participants moderately agree that French limits students' creativity in science classes. However, the mode being 5 suggests that a considerable number of participants strongly agree with this statement.

Efficacy in Instructional Strategies

Item 4: *'I believe that the French language makes it difficult for me to gauge students' comprehension.'* Participants' median and mode responses indicate that they generally agree that using French as a language in the classroom poses challenges in assessing students' comprehension.

Item 5: *'I believe that the French language makes it difficult for me to craft good and comprehensible questions for my students.'* The median and mode responses for this item are 3, suggesting that participants are somewhat neutral on this statement. It indicates a moderate level of agreement that the French language poses difficulties in crafting good and comprehensible questions for students.

Item 6: *'I believe that the French language makes it difficult for me to adjust my lessons to the proper level of individual students.'* Participants' median and mode responses suggest a moderate agreement that using French in the classroom makes it challenging to tailor lessons to individual students' needs and learning levels.

Item 7: *'I believe that the French language makes it difficult for me to provide an alternative explanation when students are confused.'* The median response of 4 indicates moderate agreement, while the mode being 5 suggests that there is a substantial number of participants who strongly agree that the French language makes it difficult to provide alternative explanations when students are confused.

Item 8: *'I believe that FMI policy makes my teaching of science less effective.'* Participants' median response of 4 suggests a moderate level of agreement that FMI policy affects the effectiveness of their science teaching. The mode being 5 indicates that a significant number of participants strongly agree with this statement.

Item 9: *'I believe that FMI policy limits classroom interaction and therefore obstructs knowledge construction.'* Participants' median and mode responses of 4 suggest a moderate level of agreement that FMI policy limits classroom interaction. This indicates that many participants believe that the FMI policy restricts opportunities for students to actively engage with the material, participate in discussions, and interact with their peers during the learning process. The mode being 4 signifies that a significant number of participants hold this view strongly. The participants' belief that the FMI policy obstructs knowledge construction suggests that they feel the policy might hinder students' abilities to construct and develop their understanding of the subject matter through active participation and collaborative learning experiences in the classroom.

Efficacy in Classroom Management

Item 10: *'I believe that the French language makes it difficult for me to deal with disruptive behaviour.'* The median response of 3 suggests that respondents were equally split over the claim that using the French language in the classroom poses difficulties in managing disruptive behaviour. Participants' responses indicate that they do not perceive a link between the use of French and handling disruptive behaviour effectively. Put differently, they do not believe that language barriers, specifically using French, may impact their ability to manage disruptive behaviour. Hence, the mode being 2 indicates that a considerable number of them strongly disagree with this statement.

Item 11: *'I believe that FMI policy makes it difficult to manage class time effectively.'* Participants' median and mode responses of 4 indicate a moderate agreement that the FMI policy poses challenges in managing class time effectively. They perceive that the FMI policy may create constraints that affect their ability to manage and allocate class time efficiently. The policy, therefore, may have implications for the pace and content coverage in their lessons, potentially impacting the depth of instruction and student learning outcomes.

Overall, the results suggest that participants believe that pupil engagement becomes a challenge when French is used as MoI. Equally, the results indicate that French affects science teachers' efficacy in using some instructional strategies such as gauging comprehension, adjusting lessons, and providing alternative explanations. Although French is not believed to impact teachers' handling of disruptive behaviour, it is perceived to affect other aspects of classroom management abilities, especially managing time.

Correlation Analysis

Self-Efficacy and Demographic Variables

Science teachers' self-efficacy negatively correlated with gender (r = -.071, p = .626), academic qualifications (r = -.196, p = .176) and subject-matter taught (r = -.269, p = .062). However, all these correlations are statistically non-significant as the *p-value* was $p > 0.05$. Assigned classroom level positively correlated with teachers' self-efficacy but the correlation was statistically non-significant ($p > 0.05$). In contrast, age (r = .293, $p < 0.05$) and teaching experience (r = .329, $p < 0.05$) were the only two variables that showed a positive and statistically significant correlation with self-efficacy. These results indicate that when age and experience increase, science teachers' self-efficacy for the use of French to teach scientific subjects increases, too.

Table 5

Self-efficacy correlations with background variables

	Age	Gender	Experience	Subject	Education	Class Level
Pearson *r*	.293*	-.071	.329*	-.269	-.196	.179
Sig. (2-tailed)	.041	.626	.021	.062	.176	.219

Note. The asterisk (*) indicates that correlation is significant at the 0.05 level (2-tailed).

Comparison of Subgroups

LES vs Maths Teachers

An independent samples *t*-test was conducted to compare the mean scores of LES and Maths teachers on self-efficacy for using French to teach science. The *t*-test (t (149) = 1.91, p = .06) revealed that the mean difference between LES teachers (M = 22.23, SD = 6.63) and Maths teachers (M = 18.59, SD = 3. 96) is statistically non-significant since the *p*-value of the test was above the accepted level of significance 0.05. These results indicate that there is no statistically significant difference between LES and Maths teachers concerning their sense of self-efficacy for using French as a medium of instruction.

Discussion

What Are Moroccan High School Science Teachers' Self-Efficacy Beliefs Regarding the Use of French as A Medium of Instruction?

Overall, Moroccan science teachers generally show low self-efficacy beliefs for the use of French as MoI for teaching science subjects. The minimum average score was 11.09 and the maximum was 38.18. The median of the average score was 20.36 and the mode was 23.18. The analysis of the participants' performance on the items has demonstrated that the use of the French language has a negative impact on the self-efficacy beliefs of the majority of science teachers as exemplified by item 8 with which 65% (cumulative) of the respondents either agreed or strongly agreed as shown in the table below.

These teachers believe that the FMI policy raises challenges associated with student engagement and the unobstructed employment of various instructional strategies. They believe that French negatively impacts their teaching ability to, for instance, gauge students' comprehension and adapt lesson plans to suit the needs of learners. Additionally, French is also believed to affect teachers' classroom abilities. particularly time management. These outcomes contribute to a deeper understanding of the complexities that arise in educational settings where a foreign language (usually L2) is employed as the MoI and underscore the importance of attending to language-related issues in science classrooms to increase pedagogical effectiveness.

What Is the Impact of Demographic Variables on Their Self-Efficacy Beliefs?

Results of the correlation analysis found that of all the other background variables only science teachers' age and teaching experience ($r = .293$, $p < 0.05$; $r = .329$, $p < 0.05$, respectively) showed a positive and statistically significant correlation with self-efficacy beliefs for the use of French as MoI. As far as these two variables are concerned, the results of the present study are congruent with other studies of teacher self-efficacy (e.g., Shaukat et al., 2019; Penrose et al., 2007). However, given the contradictory nature of the results obtained by research on teacher self-efficacy, our results are incongruent with several other studies (e.g., Tzovla et al., 2022; Azar, 2010; You et al., 2019; Mesa et al., 2020).

The positive correlation found between teachers' self-efficacy and the length of their teaching experience is not in line with Bandura's theory. Bandura (1997) claims that self-efficacy beliefs tend to become fixed once established. On the contrary, this study found that teachers' self-efficacy for FMI seems to grow with more experience, which indicates that self-efficacy beliefs are dynamic and not fixed. Research in the field of science education, namely the use of inquiry-based teaching found similar results concerning self-efficacy beliefs and teaching experience (e.g., Shahat et al., 2022). All things considered, we should bear in mind that demographic variables are not strong predictors of teachers' self-efficacy beliefs (Tschannen-Moran & Hoy, 2006, p. 952).

Is There a Difference in Self-Efficacy Beliefs for The Use of French as MoI in Maths and LES Teachers?

The results of this study showed that there is no statistically significant difference between LES and Maths teachers (M = 22.23, SD = 6.63; M = 18.59, SD = 3. 96, respectively) in their sense of self-efficacy beliefs for the use of French as a language of instruction (t (149) = 1.91, p = .06). Both groups showed low self-efficacy for FMI in science classrooms. The mean of the average score of self-efficacy for LES was (M = 22.24) and for Maths teachers it was (M = 18.60). It seems that both groups view French as a hurdle that obstructs the effective teaching of science subjects regardless of what these subjects are. This also may point to an underlying negative attitude towards the French language when used as a medium in teaching science. These results do not seem to support the claim that teacher efficacy is 'subject matter specific' (Tschannen-Moran et al., 1998, p. 790).

Is There a Correlation Between Language Proficiency and Science Teachers' Self-Efficacy?

As stated earlier, the results showed that there was no statistically significant correlation between science teachers' language proficiency and their self-efficacy beliefs for the use of French as a medium to teach science (Table 6). Most studies that explored this relationship between teacher language proficiency and self-efficacy focused on language teachers and we could not identify any study that looked at the interaction between these two variables in science teachers. Research on language teachers found that language proficiency does have an impact on self-efficacy beliefs (e.g., Sabokrouh, 2013; Faez & Karas, 2017; Choi & Lee, 2016; Yilmaz, 2011; Eslami & Fatahi, 2008). However, the study by Choi & Lee (2016) claims that although language proficiency and self-efficacy might be interdependent, they are in fact two independent constructs. The results of the present study seem to support Choi & Lee's (2016) claim since no systematic relationship could be found between science teachers' level of language proficiency and their self-efficacy beliefs for the use of French as a language of instruction.

Table 6

Correlation between teachers' self-efficacy and language proficiency

Variables	Pearson *r*	Sig.
Teachers' Self-efficacy & language proficiency	.014	.926

Thus, although science teachers' self-efficacy for the use of French was low. it was not because of their language proficiency. The overwhelming majority have a positive perception of their proficiency as 77.6% of the participants described their proficiency in French as 'good', 18.4% as 'average' and 4.1% as 'very good'. One possible explanation for these results is that science teachers hold a negative attitude toward the French language (Sabokrouh, 2013) or it is because probably they have a negative perception of their students' language proficiency which tends to be low in Moroccan students (Bouziane & Rguibi. 2018; Kaddouri, 2018). Teachers' performance on item 5 (*'I believe that the French language makes it difficult for me to craft good and comprehensible questions for my students'*) showed that the mode was (3), which means that the majority (34.7%) were neutral towards this item. This indicates that they believe that the difficulty of asking good questions (related to language ability) is not because of their language proficiency. Hence, this interpretation of the results suggests that science teachers' low self-efficacy cannot be attributed to their proficiency which they perceive as good. This, therefore, corroborates the correlation results obtained where proficiency was not found to relate to self-efficacy unlike results obtained from other studies in EMI contexts (e.g., Wang, 2021).

Conclusion and Implications

Using a quantitative research design, this study investigated Moroccan science teachers' self-efficacy beliefs for the use of French as a medium of instruction in the science classroom. It tried to uncover the impact of adopting the FMI policy on teachers' perceived sense of self-efficacy for teaching scientific subjects and to show how their self-efficacy correlates with several other variables. The results of the study indicated that the use of the French language has a negative impact on science teachers' perceived self-efficacy. Age and teaching experience were found to systematically correlate with self-efficacy beliefs which seemed to move in the same direction of these two background variables. In contrast, language proficiency did not show any positive correlation with teachers' self-efficacy.

The results of this study imply that the MoI used in science classrooms is of paramount importance to the teaching-learning process as it might negatively affect teachers' sense of self-efficacy for teaching science and, therefore, influence the learning outcome of their students. Given the results concerning age and experience variables, they indicate that more support should be provided to novice teachers in particular as they are reported to have fluctuating self-efficacy beliefs at the beginning of their career (Tschannen-Moran & Hoy, 2006). As self-efficacy in this study did not correlate with teachers' language proficiency, this implies that teachers need more training on the use of language for instructional purposes. In this regard, the distinction between classroom language and general language proficiencies would be helpful (Wang, 2021) and any professional development programs should enable science teachers to draw this distinction since these programs do usually improve science teachers' self-efficacy (Özdilek & Bulunuz, 2009) and even spur them towards adopting innovative science teaching approaches such as inquiry-based teaching (Ladachart et al., 2022).

The study, however, has many limitations. The sample chosen for this study is relatively small and may have affected the variability of the data and it will be, therefore, difficult to generalize the results to the whole science teachers' population. Moreover, data in this study was not triangulated and any future papers would benefit from combining psychometric scales with interviews, vignettes or Q-methods. Another potential problem in this study is the use of self-reported proficiency which may not exactly reflect teachers' actual linguistic competence. That said, future research can explore the combined effect of MoI and other contextual factors on science teachers' self-efficacy. Also, research can explore the impact of the use of a given medium of instruction on students' self-efficacy.

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Methodology for integrating socio-humanitarian safety into the training of future chemistry teachers

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ABSTRACT

This study explores the integration of socio-humanitarian safety components into the chemistry curriculum for secondary education, emphasizing how contextual and competency-based assessments can enhance the preparedness of future chemistry teachers. Employing a mixed-methods approach, the research evaluates the effectiveness of traditional, contextual, and competency-oriented assessment methods in measuring and fostering key competencies among 11th-grade chemistry students. Quantitative data were gathered from traditional assessments, contextual tasks, and the Unified National Testing (UNT), while qualitative insights were obtained from teacher interviews and classroom observations. The findings reveal significant discrepancies between traditional assessment scores and those from contextual and competency-based tasks, with weak correlations between traditional methods and both contextual ($r = 0.48$) and competency-oriented assessments ($r = 0.43$). A moderate correlation ($r = 0.65$) was observed between contextual tasks and competency-oriented tests, suggesting that these methods are more aligned with practical, application-based learning. While traditional assessments effectively evaluate theoretical knowledge and show a strong correlation with UNT scores ($r = 0.83$), they are insufficient for measuring higher-order competencies. The study underscores the necessity for a balanced assessment framework that incorporates both conventional and innovative methods to fully capture the spectrum of student competencies essential for socio-humanitarian safety in science education. These findings have significant implications for curriculum design, indicating that a diversified assessment approach can better prepare students for real-world challenges by fostering a comprehensive understanding of chemistry beyond rote memorization.

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Introduction

The effectiveness of natural science teachers has been extensively explored in educational research. Adu-Gyamfi (2020) and Ambusaidi Al-Hajri and Al-Mahrooqi (2021) have investigated the qualities of effective natural science educators. Magnusson, Krajcik, and Borko (1999) introduced the concept of Pedagogical Content Knowledge (PCK) to understand the specialized knowledge required by science teachers for effective teaching practices. Chan and Hume (2019) conducted a comprehensive review of empirical studies examining science teachers' PCK. The importance of "relevance" in science education and its implications for curriculum design have been discussed by Stuckey et al. (2013). Additionally, Hui Cao et al. (2017) analyzed methodologies for developing research activities in the training of future teachers using information resources.

A robust methodology is crucial for ensuring the socio-humanitarian safety of students in the training of future chemistry teachers. Integrating educational technologies, such as the Technological Pedagogical Content Knowledge (TPACK) framework, is essential for developing teachers' competence in using technology to enhance learning experiences (Zimmermann et al., 2021). Innovative teaching approaches, including project-based learning and STEM education philosophies, have been effective in engaging students and preparing them for professional careers in chemistry (Domenici, 2022). Addressing classroom diversity is another critical aspect, with training programs focusing on equipping teachers to effectively teach heterogeneous and diverse student populations (Tolsdorf et al., 2018). Continuous professional development is vital for chemistry teachers to remain current with best practices and innovative teaching methods, as demonstrated by research on green chemistry education (Cannon et al., 2023).

Based on a review of the literature, several key strategies have been identified:

1. Integration of Educational Technologies: Future chemistry teachers need to enhance their technological pedagogical content knowledge (TPACK) to improve learning experiences (Zimmermann et al., 2021). This includes developing self-efficacy, a positive attitude, and competence in lesson planning using educational technology.
2. Innovative Teaching Approaches: Employing project-based learning activities and STEM education philosophies effectively trains future chemistry teachers, enhancing their skills in engaging students and encouraging active learning (Domenici, 2022).
3. Addressing Classroom Diversity: Training programs should focus on preparing teachers to effectively teach heterogeneous and diverse classrooms, developing their informational and diagnostic competencies, and equipping them with skills to manage diverse student needs (Tolsdorf et al., 2018).
4. Professional Development: Continuous professional development is crucial for teachers to stay current with best practices and innovative teaching methods. Green chemistry teaching, sustainable practices, and formative assessment methods can enhance teaching and improve student outcomes (Cannon et al., 2023).
5. Safety: Ensuring that teachers are knowledgeable about and adhere to laboratory safety protocols is essential. Safety training, providing necessary equipment, and fostering a culture of safety contribute to the socio-humanitarian safety of students (Hussein & Shifera, 2022).
6. Contextual Learning: Integrating real-world contexts, such as pharmacology topics, into chemistry lessons makes the subject more interesting and relevant, improving learning for both teachers and students (Schwartz-Bloom et al., 2011; Marifa et al., 2023).
7. Building Resilience: Training future chemistry teachers to increase their resilience to adversity, especially in diverse social environments and resource-limited settings, equips them to handle challenges effectively (Palermo et al., 2021).

By integrating these approaches, a comprehensive methodology can be developed to ensure the socio-humanitarian safety of students in the preparation of future chemistry teachers. This methodology should encompass professional development, innovative teaching practices, diversity management, identity development, evidence-based education, contextual learning, and sustainability education to create a holistic curriculum for chemistry teachers.

Socio-humanitarian security has emerged as a significant area of study, with its components outlined in the United Nations Development Programme report (1994) and further explored by scholars such as Kazakov (2013), Zubarevich (2020), Baluev (2004), and Prokhorov (2010). However, there is a notable gap in the literature specifically addressing the socio-humanitarian security of Kazakh society. This gap highlights the critical need for studies focusing on the unique socio-humanitarian challenges faced by Kazakhstan. Therefore, this study aims to develop a scientifically grounded, pedagogical, multi-vector system tailored to the Kazakh educational environment. This system is designed to equip natural science teachers with the necessary skills and knowledge to incorporate socio-humanitarian security components into their professional activities, addressing an urgent and previously underexplored area of educational research.

In contemporary society, individuals consistently encounter a multitude of threats, ranging from explicit to covert. Considering the continual evolution of society and its processes of socialization and interaction, aspects of socio-humanitarian security become essential components imparted to successive generations. Consequently, the paramount aspect of preparing future professionals lies in ensuring personal security across all fields of their aspirations, facilitating the comprehensive development of their potential and professional competencies. Safeguarding and fostering resilience in students throughout their professional development are integral to their growth and educational journey, facilitating their harmonious integration into society and the preservation and transmission of their personal and communal values, as well as the safe use of chemicals (European Commission, 2011).

Before becoming professionals, individuals must transition from being goal-oriented students to highly motivated future specialists. Therefore, the role of the teacher is crucial in guiding and orienting students within contemporary, information-rich, and socially integrated societies. From the perspective of socio-humanitarian security, future educators should aid students in navigating their reality and contribute to creating conditions in which they can utilize the knowledge they have gained, both in selecting their professional pursuits and in promoting well-being within their community and environment.

Teachers of natural sciences—biology, geography, chemistry—possess skills in establishing patterns and identifying cause-and-effect relationships among the components of nature, society, and economy. Consequently, as professionals with broad expertise, they are particularly equipped to instill the foundations of socio-humanitarian security in students. However, achieving optimal outcomes in preparing future chemistry educators necessitates enhancements and refinements to the educational process. Specifically, it involves developing and implementing an educational model focused on equipping chemistry educators to adopt a competency-based approach to teaching, serving as a catalyst for socio-humanitarian security within the "nature-human-society" paradigm.

Modern education and the training of pedagogical students must be humanitarian-centric, integrating societal advancements alongside personal achievements, experiences, and subject-specific competencies. This approach serves as the foundation for ensuring developmental security, livelihood, and purposeful engagement in both professional and personal realms (State Program for Regional Development for 2020–2025 of the Republic of Kazakhstan, 2019). Therefore, developing a scientifically grounded, pedagogical, multi-vector system aimed at preparing natural science teachers to integrate socio-humanitarian security components into their professional practices is both relevant and necessary. This study aims to provide theoretical and methodological justification and support for a model of teacher training in natural sciences that implements the principles of socio-humanitarian safety within the "nature-human-society" paradigm in the educational process.

Review of the Current Literature

The integration of socio-humanitarian security into the training of future chemistry teachers is a multifaceted issue that requires addressing several key variables: educational technologies, innovative teaching approaches, class diversity, professional development, safety, and contextual learning.

The use of educational technologies in teaching is crucial for modern education. The TPACK framework, which integrates technological, pedagogical, and content knowledge, is fundamental for developing teachers' competence in using technology effectively (Mishra & Koehler, 2006). Studies have shown that technology-enhanced learning environments can significantly improve student engagement and learning outcomes (Koehler et al., 2013). For instance, Koehler and Mishra (2009) demonstrated that teachers who are proficient in TPACK can create more interactive and engaging lessons. Similarly, Chai, Koh, and Tsai (2013) emphasized the importance of developing teachers' technological pedagogical content knowledge to enhance their instructional practices. The integration of digital tools in teaching practices can also foster students' critical thinking and problem-solving skills (Hsu, 2016; Harris, Mishra, & Koehler, 2009).

Innovative teaching approaches, such as project-based learning and the STEM teaching philosophy, are effective in engaging students and preparing them for future professional activities. Project-based learning has been shown to enhance students' critical thinking, collaboration, and problem-solving skills (Bell, 2010; Thomas, 2000). The STEM approach, which integrates science, technology, engineering, and mathematics, encourages students to apply their knowledge in real-world contexts (Beers, 2011). Studies by Capraro, Capraro, and Morgan (2013) and Bybee (2010) highlight the benefits of STEM education in developing students' interest and proficiency in science and technology. Moreover, the use of inquiry-based learning, which involves students in the process of scientific investigation, has been found to improve their understanding of scientific concepts and processes (Hmelo-Silver, Duncan, & Chinn, 2007; Minner, Levy, & Century, 2010).

Addressing class diversity is essential for creating inclusive and equitable learning environments. Training programs should focus on preparing teachers to effectively teach heterogeneous and diverse classrooms. Differentiated instruction, which involves tailoring teaching methods to meet the diverse needs of students, has been shown to improve student learning outcomes (Tomlinson, 2001; Subban, 2006). Additionally, culturally responsive teaching, which recognizes and respects the cultural backgrounds of students, can enhance their engagement and academic achievement (Gay, 2010; Ladson-Billings, 1995). Research by Banks et al. (2001) and Nieto (2010) underscores the importance of multicultural education in promoting social justice and equity in schools.

Continuous professional development is vital for teachers to stay current with best practices and innovative teaching methods. Professional development programs that focus on reflective practice, collaboration, and ongoing learning can enhance teachers' instructional skills and knowledge (Darling-Hammond, Hyler, & Gardner, 2017). Studies have shown that effective professional development can lead to improved teaching practices and student learning outcomes (Desimone, 2009; Guskey, 2002). Research by Garet et al. (2001) and Loucks-Horsley et al. (2010) emphasizes the importance of sustained, collaborative, and content-focused professional development for teachers.

Socio-humanitarian security is a multidimensional concept that extends the traditional notion of security beyond military and political realms to include social, economic, environmental, and human rights dimensions (UNDP, 1994). It emphasizes the protection of individuals and communities from threats that undermine their well-being and dignity, such as poverty, disease, environmental degradation, and social injustice (Kazakov, 2013; Zubarevich, 2020). In the context of education, socio-humanitarian security involves equipping learners with the knowledge, skills, and values necessary to navigate complex societal challenges and contribute to the creation of a more just and sustainable world (Bourn, 2016). Research indicates that embedding socio-humanitarian themes into the curriculum enhances students' ability to critically analyze societal issues and develop a sense of global citizenship (Osler & Starkey, 2010). For example, integrating topics like sustainable development, social justice, and ethical implications of scientific advancements into science education can promote a more holistic understanding of the subject matter (Zeidler & Nichols, 2009). This approach aligns with the concept of education for sustainable development (ESD), which UNESCO (2017) advocates as a means to empower learners to take informed actions for environmental integrity, economic viability, and a just society. Safety in the laboratory and classroom is paramount, requiring comprehensive safety training for teachers. Teachers need to be knowledgeable about and follow laboratory safety protocols to ensure the well-being of their students (Hussein & Shifera, 2022). Research has shown that safety training can reduce the risk of accidents and injuries in the laboratory (Hill & Finster, 2016; Kuntzleman & Rohrer, 2017). Additionally, fostering a culture of safety in schools can promote students' awareness and understanding of safety practices (Carmichael, 2013; Viswanathan et al., 2016).

The contemporary conditions of life and activity have underscored the necessity for students to develop personal qualities conducive to their professional and social mobility within a dynamically evolving society. However, the preparedness level of graduates from schools and universities does not align with these demands. Today, the education and training of pedagogical students must be practice-oriented and integrative, based on the introduction into education not only the achievements of society but also the individual's own achievements, her object-subject experience, as the basis for the safety of development, vital activity, and goal-setting in work and life. That is why, starting from the modern requirements of society and the education system as an integral part of it, the issues of multi-vector scientifically based systematic training of a future chemistry teacher based on integrativity and interdisciplinarity are becoming increasingly relevant.

Contextual learning involves integrating real-world contexts into the curriculum to make learning more relevant and engaging for students. Studies have shown that contextual learning can improve students' understanding and retention of scientific concepts (Berns & Erickson, 2001; Johnson, 2002). For example, integrating pharmacology topics into chemistry lessons can make the subject more interesting and relevant for students (Schwartz-Bloom et al., 2011). Research by Herrington and Oliver (2000) and Brown, Collins, and Duguid (1989) emphasizes the importance of situated learning, where students learn through authentic activities in real-world contexts.

While significant research has been conducted on various aspects of teacher education and innovative teaching practices (Darling-Hammond, 2006; Guskey, 2002), there remains a notable gap in the literature concerning the integration of socio-humanitarian security into the training of future chemistry teachers. Although there is a growing focus on integrating socio-humanitarian security within educational frameworks in response to increasing global awareness of human security issues (UNDP, 1994), most studies have concentrated on specific teaching strategies or professional development programs without addressing the comprehensive incorporation of socio-humanitarian components (Gulikers et al., 2004; Shavelson et al., 2008). Scholars like Kazakov (2013) and Baluev (2004) have emphasized the need to embed social security concepts into education to prepare students for societal challenges, yet there remains a notable gap in addressing these components within teacher training, specifically in chemistry education. This gap underscores the critical need for research that develops a pedagogical model tailored to integrating socio-humanitarian security within the educational framework for chemistry teachers.

Studies have increasingly demonstrated the value of competency-based models for teacher education in achieving these goals. For instance, Gulikers et al. (2004) propose an authentic assessment framework to foster real-world application of knowledge, while Voogt and Roblin (2012) argue that integrating competencies related to social responsibility and security equips teachers with broader skills necessary for a globalized world. Such findings are supported by Darling-Hammond (2006), who asserts that comprehensive teacher education, which includes socio-humanitarian training, can prepare teachers to address complex, real-world issues in the classroom.

Despite these advancements, existing studies often focus on broad educational strategies without fully addressing the specific integration of socio-humanitarian security into chemistry education. This highlights a critical research gap, particularly in regions like Kazakhstan, where specific socio-humanitarian challenges are uniquely pronounced (Mukatayeva, 2023; Prokhorov, 2010). The limited research on Kazakhstan's socio-humanitarian context underscores the importance of developing specialized teacher training programs that integrate these components to address the country's unique educational and societal needs (Stuckey et al., 2013). A synthesis of these studies suggests that developing a pedagogical model tailored for chemistry teachers-focused on socio-humanitarian security-could significantly contribute to both educational quality and national stability, aligning with the goals set forth by global and regional educational frameworks.

The relevance of this research is underscored by substantial shifts in the requirements currently placed on graduates of both schools and universities by the professional community and educational as well as social environments (Kazakov, 2013). In contemporary circumstances, there is a growing imperative for students to cultivate personal qualities that foster their professional and social mobility. Therefore, the aim is not solely acquiring knowledge but also developing the readiness to perform particular roles, which stands as a key goal for both tertiary and secondary education systems (Zubarevich, 2020; Baluev, 2004; Prokhorov, 2010).

In order to systematically prepare future chemistry teachers for the implementation of components of socio-humanitarian security in their future professional activities, we believe it is necessary to examine these research questions:

1. What are the key components of socio-humanitarian security that need to be integrated into the training of future chemistry teachers?
2. How can a competency-based approach be effectively implemented to enhance socio-humanitarian security within the "nature-human-society" paradigm?
3. What are the most effective methodologies and practices for integrating socio-humanitarian security into the educational process for chemistry teachers?
4. How do future chemistry teachers perceive the importance and implementation of socio-humanitarian security in their professional practices?
5. What are the challenges and barriers faced by educators in integrating socio-humanitarian security components into their teaching?

Methodology

Research Design

This study employed a mixed-methods approach, integrating both qualitative and quantitative research methods to comprehensively assess the chemical competencies of students within the "School - Pedagogical University" system. Mixed-methods research is particularly suitable for this study as it allows for the collection and analysis of diverse types of data, providing a more holistic understanding of the educational outcomes (Creswell & Plano Clark, 2018). This approach enabled the triangulation of data, enhancing the validity and reliability of the findings. To assess the quality of the results of educational activities of students in the "school - pedagogical university" system, methods and tools were used to identify the results of mastering the educational program from the perspective of competence-oriented requirements for the quality of their training. As a result of the teacher's control and evaluation activities, the total rating score of students will be considered, on the basis of which the achieved level of chemical competencies was determined. At the stage of the search experiment, it was found that traditional methods and controls are insufficient to measure the competencies of students, and a methodological approach was used to obtain reliable results on the quality of preparedness of graduates of schools and universities.

The methodological approach allows for considering the results of both external and internal control, which is carried out by the teacher. At the same time, the teacher's controlling activity is realized through observation, oral and written assessment, analysis of the performance of contextual tasks, tests, and situational tasks.

Participants and Context

During the exploratory research phase, the existing system for assessing the educational outcomes of students and learners was analyzed to determine the professional readiness of graduates from pedagogical universities for their future careers and the preparedness of students from secondary schools to pursue further education (particularly in the field of chemistry). For the organization of control and assessment activities, a criteria base and diagnostic indicators were developed for teachers. Table 1 shows demographic information on the results of students' mastery of chemistry in the experimental groups.

Table 1

Information on the results of students' mastery of chemistry in the experimental groups

№	Academic Discipline	The number of students in the class	The number of students assessed on			The percentage of academic achievement	The Mean score	The percentage of students achieving grades "5" and "4"	The indicator of teaching effectiveness
			5	4	3				
1	Students of the 10th grade class A, Lyceum №12, Almaty	22	12	9	1	100	4,5	95	0,5
2	Students of the 10th grade class B, Lyceum №12, Almaty	18	8	8	2	100	4,3	88	0,46
3	Students of the 10th grade class V, Lyceum №12, Almaty	18	3	8	7	100	3,7	61	0,32
4	Students of the 10th grade class G, Lyceum №12, Almaty	24	10	5	9	100	4	62	0,69
5	Students of the 10th grade class A, Gymnasium №178, Almaty Region	21	4	9	8	100	3,8	62	0,34

Monitoring studies were conducted in the academic years 2021-2022 and 2022-2023. In 2021, an experimental group was formed, consisting of students from the 10th grade of School №12 in Almaty and School №178 with an emphasis on natural sciences in the Almaty region. In the academic year 2022-2023, this group of students was in the 11th grade, and at the end of this period, the level of formation of their chemical competencies was assessed. In the general practice, 103 students and 15 instructors participated, with ages ranging from under 35 years old to over 50 years old.

Research Instrument

The measurement and evaluation of chemical competencies were conducted using both conventional pedagogical methods and innovative assessment tools, followed by a comparison of the obtained data and their statistical analysis. Insignificant discrepancies between the control results obtained with traditional and innovative instruments suggest that they assess the same content elements, indicating consistency in the obtained data. However, significant differences between the control results obtained with traditional methods and innovative instruments may indicate either the unreliability of the data obtained or the unsuitability of certain instruments for assessing the required educational outcomes of students.

In the development of control and measurement materials, the aim was to identify elements not only of knowledge but also of the activity components of competencies. During the descriptive phase of the research, it was established that traditional methods and means primarily assess knowledge, often at a reproductive level, as well as the ability to replicate prescribed actions.

Contextual tasks are contained in the control and measurement materials developed for the International PISA Education Quality Study. Most researchers classify contextual tasks as non-standard tasks that can activate the cognitive activity of schoolchildren (Aligberova & Stepin, 2002; Pichugina, 2004). Therefore, contextual tasks allow us to assess the quality of students' knowledge, not the amount of content mastered. When developing contextual tasks, the following rules were followed:

- The personal significance of the assignment for students, since the content is related to everyday life or professional activity;
- The complexity of control achieved by a set of tools used to evaluate a given amount of content;
- Creating conditions for the manifestation of independent thinking. At the same time, the context of the task should not contain hints that contribute to solving the problem or may provide several solutions, of which at least one does not meet the given situation.

Considering the possibilities of contextual tasks, Pankova (2002) notes that they can be applied in the context of competence-based education. This conclusion is justified by the fact that contextual tasks require independent thinking and the presence of formed experience in performing actions. Situational tasks offered to measure chemical competencies are mainly practice-oriented or professionally oriented.

Pedagogical Modeling

The implementation of the above-mentioned steps will contribute to enhancing the effectiveness of the educational process through the application of modern teaching methods and technologies in natural science disciplines. Additionally, creating conditions that ensure the development of socio-humanitarian security aspects in future chemistry teachers and their integration into the educational process of secondary education institutions is essential (Mukatayeva, 2023). Promoting a sense of satisfaction by ensuring socio-humanitarian security as a specific state of protection of the vital interests of individuals is also a key outcome. Questions of socio-humanitarian security within the framework of natural science education have their distinctive features depending on the subject.

Modeling is understood as the study of objects based on their corresponding models, as well as the construction of models of real-world objects and processes in order to explain and predict their properties, characteristics, and patterns of functioning. The following functions of pedagogical modeling can be distinguished:

- Scientific consistency and consistency in the search for optimal and pedagogically appropriate solutions and organized pedagogical processes;
- Implementation of the ideas of humanism, health savings, productivity, creativity, and other necessary values in the system of socio-educational and professional-labor relations;
- Concretization and updating of all components in the theoretical and implemented pedagogical processes;
- Flexible management of personal development opportunities through specially developed resources and products of scientific and pedagogical activity (Vikulina, 2013).

According to the structural mechanism, structural and functional models are most often used in pedagogical modeling, in the construction of which the object is considered as an integral system, including component parts, components, elements, subsystems. The parts of the system are connected by structural relations describing subordination, logical and temporal sequence of solving individual tasks (Kozyrev, 2021). The following stages of creating a pedagogical model are distinguished: structuring the object of pedagogical modeling (selection of elements, selection of a set of properties that ensure the completeness of the description of various aspects of the studied pedagogical phenomenon and building a system of relations between the selected elements; building a formalized scheme of the educational process, establishing a system of pedagogical parameters and components, taking into account those factors that are taken into account during formalization; identification of the model is the definition of interaction and interdependencies within the structure of the model, ensuring the most effective implementation of the pedagogical phenomenon (Zakrevskaya, 2011).

The term "training model" is most often used. In the context of the implementation of the competence approach, this model is considered as an educational process that prepares students to solve professional problems. The training model is a dynamic system with a certain content and structure. The correct choice of methodological and methodological foundations for teaching disciplines, as a factor of high-quality training, contributes to the construction of a model, the implementation of which allows you to achieve the planned result.

The formation of the concept of socio-humanitarian safety takes place in the educational process, which is based on the methodology of the competence approach. It is necessary to form competencies among future chemistry teachers that allow them to form the concept of socio-humanitarian safety among students in institutions of general secondary education. In the curricula, expand the list of competencies formed by students by including competencies related to socio-humanitarian safety. Student must:

- Have a holistic understanding of the components of socio-humanitarian safety;
- Be able to analyze the causes of instability and predict solutions that contribute to achieving socio-humanitarian safety;
- Be ready to implement the components of socio-humanitarian safety in the educational process through effective pedagogical approaches;
- Be able to design the educational process taking into account the interdisciplinary nature of the disciplines taught and the versatility of aspects of socio-humanitarian safety.

Data Analysis

In order to organize the process of measuring competencies, the following axioms were adopted:

- Competencies can be measured indirectly, so it is important to create conditions for their manifestation.

- There are always multiple external manifestations (indicators) describing latent characteristics, which are subject to measurement.

- The achievable accuracy of measurement is determined by the amount of prior information available about the competency as the object of study.

When developing the methodology, we adhered to the law of diversity: the variety of assessment tools should be adequate to the content of the object being measured, through which various educational tasks are solved. In this regard, the following were used in the development of the methodology:

- A comprehensive approach, involving the application of commonly accepted methods and means of control along with innovative measuring instruments, allowing for the most complete identification and measurement of competency formation;

- A systemic approach, involving: the organization of monitoring studies to analyze the dynamics of competency formation and development during the learning process; determining the level of formation of chemical competencies at the final stage of educational program completion. For this purpose, an accumulative system for recording results and calculating the cumulative rating score was applied. Prior to conducting experimental activities to study the validity of the developed methodology, preparatory work was carried out, including identifying the content of chemical competencies, selecting appropriate tools, developing control and measurement materials, and assessing their reliability. The experiment was conducted in the context of changes in the legislation of the Republic of Kazakhstan regarding the implementation of the new format of the Unified National Testing (UNT) (2024) as part of the final state certification of graduates of secondary schools. The results of UNT were considered as an indicator of students' preparedness quality, and the control and measurement materials were regarded as instruments for its measurement. It was important for us to determine whether the competency formation could be assessed using these control and measurement materials, thus the results of UNT in chemistry for students in the experimental groups were compared with the results of comprehensive measurement.

Individual scores underwent statistical processing to determine Mean values, which were considered as generalized indicators of achieving the set goals. Subsequently, they were compared, and the Pearson correlation coefficient (%) was calculated. Competency-oriented tests, case studies, and contextual tasks were applied as innovative tools. The determination of the level of students' chemical competency formation was based on the results of monitoring and certification control and evaluation activities. Monitoring was conducted in 10th and 11th grades as part of the chemistry curriculum implementation. The indicators of students' chemical competency formation included the results of contextual tasks, competency-oriented tests, and knowledge and skills demonstrated during oral interviews and other forms of assessment. Criteria and diagnostic indicators were developed to organize the teacher's control and evaluation activities.

Results

For conducting a proper comparison, the results of quantitative assessment using contextual tasks are juxtaposed with grades on a five-point scale. In this regard, the grade "5" corresponds to a score ranging from 100% to 80% of the maximum possible; "4" - 80% - 60%; "3" - 60% - 30%; "2" - less than 30% in Table 2.

Table 2

The correspondence of measurement results to qualitative grades (based on the performance of contextual tasks)

Qualitative assessment	5	4	3	2
Score count	72-58	57-43	42-22	21-0

The results of assessing the mastery of the general chemistry curriculum by students in the 10th grade experimental groups are presented in Tables 1-3. The traditional control results were considered in terms of the Mean grade of the student, calculated based on the aggregate of marks for written and oral responses. A comparative analysis of the results of traditional assessment and the completion of contextual tasks was conducted based on correlation analysis. The statistical characteristics of the obtained results are presented in Table 3.

Table 3

Results of the assessment of the chemistry curriculum mastery by the 10th-grade students

№	Results of assessment using traditional means	Results of assessment using contextual tasks	
		Quantitative score	Qualitative grade
1.	5	34	3
2.	4	21	2
3.	5	32	3
4.	5	49	4
5.	4	15	2
6.	4	27	2
7.	4	16	3
8.	4	21	2
9.	3	15	2
10.	4	15	2
11.	5	41	3
12.	3	9	2
13.	3	28	3
14.	4	23	3
15.	3	12	2
16.	4	27	3
17.	5	16	2
18.	5	42	3

The traditional assessment results were considered in terms of the Mean score of each student, calculated based on the combination of marks for written and oral responses. A comparative analysis between the results of traditional assessment and the performance in contextual tasks was conducted using correlation analysis. Statistical characteristics of the obtained results are presented in Table 4.

Table 4

Statistical criteria for the measurement and evaluation of chemical competencies of students in the 10th grade

Results of "traditional" assessment		Results of completing contextual tasks	
Indicators	Values	Indicators	Values
Mean value	4,2	Mean value	2,97
Standard error	0,11	Standard error	0,08
Median	4	Median	3
Mode	4	Mode	3
Standard deviation	0,72	Standard deviation	0,53
Sample variance	0,52	Sample variance	0,28
Kurtosis	-0,98	Kurtosis	0,88
Skewness	-0,32	Skewness	-0,03
Number of intervals	2	Number of intervals	2
Minimum score	3	Minimum score	2
Maximum score	5	Maximum score	4
Total	168	Total	119
Account	40	Account	40
The reliability level (95.0%)	0,23	The reliability level (95.0%)	0,16

Note. *The Pearson correlation coefficient = 0.47

As seen from the tables, the calculation of the Pearson correlation coefficient yields a value falling within the interval corresponding to weak correlation between the correlated features (up to 0.3 - practically no correlation; 0.3-0.5 - weak correlation; 0.5-0.7 - moderate correlation; 0.7-1 - strong correlation). This allows us to conclude that both traditional methods and means of control and contextual tasks are used to identify and measure elements of different components of chemical competencies. The analysis shows that in the first case, mainly the mastery of theoretical knowledge is controlled, with insufficient attention paid to independent thinking, functionality, and flexibility of knowledge. From conversations with teachers, it can be concluded that educators lack sufficient instructional time to develop these qualities in students, and this issue could be addressed by increasing the amount of instructional time. To test this hypothesis, we assessed the level of formation of chemical competencies in students of Gymnasium №178 in Almaty, where chemistry is studied for 4 hours per week. Measurement of chemical competencies in this group of students was conducted using the same tools as in other experimental groups. Calculation of the initial level of their training showed that initially students of Lyceum №12 in Almaty are better prepared in the subject. Therefore, it can be assumed that they should cope more successfully with contextual tasks. However, the analysis of the performance of contextual tasks in this group of students did not confirm this assumption. It turned out that students of Lyceum №12 faced the same difficulties as other students. In particular, they do not know how to identify the knowledge necessary to solve problems, have difficulty in independently determining the method of problem-solving. The knowledge of students in this group has also not reached the required level of application and analysis, indicating a low level of formation of their activity component of competencies. The matrix of performance of contextual tasks by 10th-grade students of Lyceum №12 in Almaty is presented in Appendix 31. The obtained results were analyzed using methods of mathematical statistics, as reflected in Table 5.

Table 5

Statistical characteristics of the measurement results of chemical competencies for 10th grade "g" students, school lyceum №12, Almaty

Results of "traditional" assessment		Results of completing contextual tasks	
Indicators	Values	Indicators	Values
Mean value	3,91	Mean value	3,91
Standard error	0,18	Standard error	0,18
Median	4	Median	4
Mode	3	Mode	3
Standard deviation	0,90	Standard deviation	0,90
Sample variance	0,81	Sample variance	0,81
Kurtosis	-1,80	Kurtosis	-1,80
Skewness	0,18	Skewness	0,18
Number of intervals	2	Number of intervals	2
Minimum score	3	Minimum score	3
Maximum score	5	Maximum score	5
Total	90	Total	90
Account	23	Account	23
The reliability level (95.0%)	0,38	The reliability level (95.0%)	0,38

Note. *The Pearson correlation coefficient = 0.69

Calculation of the Pearson correlation coefficient indicates a moderate level of correlation between the correlated features. These data somewhat differ from those previously presented in Tables 4-5, which is quite understandable. The chemistry teacher in the 10th "G" grade of Lyceum

№12 in Almaty considers the development of students' chemical thinking, the enhancement of the strength and functionality of their knowledge as a priority task. However, in the conditions of the subject-knowledge model of the graduate, this task is not fully resolved, as confirmed during the research. Therefore, the volume of instructional time is not the determining factor, although undoubtedly, it is essential for improving the quality of chemical education. The research results indicate that addressing the identified task is possible based on the recognition of the competency model of the graduate and its implementation in the educational process. The methodology of a comprehensive approach to competency measurement allows considering the results not only of internal but also external control. Currently, the quality control of graduates' preparation in secondary schools is carried out during the final state certification, conducted in the form of UNT. Students from the experimental groups, including those from the 10th "G" grade of Lyceum №12, participated in UNT for chemistry (87% of the total number of students in the class). The quantitative results of the participants in UNT were compared with qualitative grades on a five-point scale. The intervals of qualitative grades were established based on the minimum number of points in chemistry determined by the Kazakhstani education system, as outlined in Table 6.

Table 6

Correspondence of unified national testing score to qualitative grade on a 5-point scale

Qualitative assessment	5	4	3	2
Score count	76-100	50-75	34-49	0-33

The analysis of the content of UNT in chemistry led to the conclusion that the majority of test tasks assessed knowledge at the level of reproduction or application by example. The test items did not include tasks with a practical orientation or requiring independent thinking. Therefore, the tests are aimed at identifying the content of the knowledge component of subject competencies and are not oriented towards the activity component. Consequently, assessing the level of formation of subject competencies using them is not feasible, and it is advisable to use other measures. One of these measures is contextual tasks, which were offered to students in the 11th grade at the end of the educational program in chemistry. The test included tasks compiled by the author and taken from the educational-methodical manual "Fascinating tasks and impressive experiments in chemistry".

1. Unloading Fertilizers: "Several tons of frozen mineral fertilizer are lying on open railway platforms. How to unload such a composition?"

2. Home Chemistry: "In A.I. Makievsky's book 'Home Chemistry,' an interesting observation is provided: '...The fairer sex often consumes vinegar in enormous quantities, either in its pure form or with other dishes to maintain a slender waistline. The goal is achieved perfectly, but along with the graceful waist, an unattractive complexion is acquired.' Consequently, excessive use of vinegar can lead not only to the appearance of a sallow complexion but also to serious poisoning. How to provide first aid to a beauty who has overindulged in vinegar, using means that do not harm health?

3. Grain Storage Treatment: "Dichloroethane is used in agriculture for disinfecting grain storage facilities. Calculate the amount of substance required to treat a room with an area of 500 m^2, if 300 g of this substance is used per square meter."

4. Toothpaste: "Calculate the mass (g) of sodium monofluorophosphate sodium triphosphate (Na2PO3) contained in a tube of toothpaste (tube mass 100 g) labeled 'Active fluoride content 0.15%". Evaluation of contextual tasks is carried out using the developed criteria outlined in Table 7.

Table 7

Approximate evaluation scheme for contextual tasks

Criteria	Evaluation criteria	Score
Correspondence of the indicated problem to the conditions of the task	- the identified problem fully corresponds to the conditions outlined in the task	2
	- the problem identified in the task is detected but does not correspond to the conditions presented in the problem statement	1
	- the problem is identified incorrectly	0
Completeness and sufficiency of the data required to solve the problem	- the student used the data provided in the problem statement, and in case of their insufficiency, conducted independent research to gather additional information	2
	- the student uses the data provided in the problem statement, but in case of their insufficiency, did not conduct a search for the necessary information	1
	- the conditions of the problem were not utilized	0
The sequence and correctness of the solution steps	- the steps of solving the problem are sequential and correct	2
	- the steps of solving the problem are sequential, but errors were made in the solution	1
	- the sequence of steps and the method of solving the problem are incorrect	0
The rationale for the solution approach	- several solution approaches are proposed, but the most rational one is chosen, which is justified by the student	2
	- one solution approach is proposed, but the choice is not justified	1
	- no solution approach is proposed	0
The completeness and correctness of the provided answer	- the answer is complete and correct	2
	- the answer is correct, but not complete	1
	- the answer is incorrect	0
The completeness and correctness of the solution presentation	- the initial data and the solution steps are presented correctly, using figures, graphs, which confirm the solution	2
	- the data and solution steps are presented correctly, but there are no diagrams, figures, or illustrations illustrating the solution	1
	- the data and solution method are not formatted correctly	0

To conduct a correct comparison between the results of contextual task performance and grades obtained through traditional assessment, the quantitative measurement results were correlated with qualitative grades in Table 8.

Table 8

Correspondence between the results of contextual task performance and qualitative grades

Qualitative grade	«5»	«4»	«3»	«2»
Quantitative result	84-68	67-51	50-26	25-0

Results of contextual task performance by students of the 11th grades in the experimental groups are presented in appendices 36-38. In addition to contextual tasks, students in the 11th grades of the experimental groups were offered competency-oriented tests at the final stage of their education. The content of the competency-oriented test is presented in section 3.3.

Multiple-choice task: (with a choice of one correct answer) The storage period of car tires at t= 20°C is 5 years, while at t= -10°C it is 13 years. What will be the storage period of these tires at 5°C?

1) 18 years, 2) 20 years, 3) 21 years, 4) 22 years, 5) 23 years

Open-ended completion task: (involves writing a short answer) For scanning the brain, 48 g of iron is required. The time required to conduct electrolysis of the iron sulfate (FeSO4) solution at a current strength of X amperes to obtain the necessary mass of pure metal is…

Task with free-form response: Discuss the environmental impact of plastic pollution on marine ecosystems and propose potential solutions to mitigate this issue

The compound with the molecular formula C3H8O underwent oxidative dehydrogenation, resulting in the formation of a product with the composition C3H6O. This substance reacts with the "silver mirror," forming a compound C3H8O2. When calcium hydroxide acts on the latter, a substance used as a food additive under the code E282 is obtained. It inhibits mold growth in bakery and confectionery products and is found in Swiss cheese. Provide the formula for E282, write down the equations of the mentioned reactions, and name all organic substances.

After determining the primary data, we conducted their scaling to obtain qualitative marks. The necessity of this procedure is explained by the fact that only in this case we can compare the quantitative scores obtained through the competency-oriented test with the results of assessment using traditional methods and means in Table 9.

Table 9

Correspondence of competency-oriented test results to qualitative marks

Qualitative grade	«5»	«4»	«3»	«2»
Quantitative result	48-38	37-29	28-14	13-0

We assumed that the competency-oriented test, as well as contextual tasks, allows for the identification of the same elements of competency content, and there should be no significant differences between the measurement results. To confirm this assumption, we used correlation analysis and calculated statistical criteria. The results of the statistical analysis are presented in Table 10.

Table 10

Statistical criteria for analyzing the measurement results of students' chemical competencies in experimental groups

Results of "traditional" assessment		Results of completing contextual tasks	
Indicators	Values	Indicators	Values
Mean value	25,431	Mean value	35,43
Standard error	1,65	Standard error	2,01
Median	27	Median	34
Mode	33	Mode	24
Standard deviation	7,94	Standard deviation	9,66
Sample variance	63,07	Sample variance	93,34
Kurtosis	-1,07	Kurtosis	-1.27
Skewness	-0,46	Skewness	0,17
Number of intervals	25	Number of intervals	31
Minimum score	12	Minimum score	24
Maximum score	37	Maximum score	55
Total	585	Total	815
Account	23	Account	23
The reliability level (95.0%)	3,43	The reliability level (95.0%)	4,17

The existence of a significant similarity in quantitative indicators is supported by a correlation coefficient value of 0.84. Therefore, our assumption has been confirmed, and these instruments are valid for measuring the content of both the knowledge and activity components of students' chemical competencies. Comparison of the results of internal assessment (contextual tasks, tests, "traditional means") and external control (national standardized testing) was conducted using methods of one-way analysis of variance and correlation analysis. The results of assessing the mastery of the educational program in chemistry by students of the 11th grade in the experimental groups are presented in Table 11.

Table 11

Measurement and assessment data of the developed content of chemical competencies of 11th grade students (Academic year 2022-2023)

№	Results of assessment using traditional means	Results of UNT (UNT) in Chemistry		Results of solving contextual tasks		Results of competency-based test	
		Quantitative result	Qualitative mark	Quantitative result	Qualitative mark	Quantitative result	Qualitative mark
1.	4	44	3	35	3	28	3
2.	3	31	3	30	3	19	3
3.	4	44	3	42	3	31	4
4.	5	53	4	39	3	34	4
5.	5	77	5	50	3	33	4
6.	3	-	-	57	4	33	4
7.	5	57	4	30	3	23	3
8.	4	59	4	27	3	21	3
9.	5	53	4	53	4	30	4
10.	3	-	-	53	4	33	4

Statistical analysis of the measurement results of the chemical competencies of the experimental group students and the calculation of the Pearson coefficient between different forms of control indicate significant differences between them, as given in Tables 12-16

Table 12

Statistical criteria for the measurement and assessment of the chemical competencies of 11th-grade students (based on the results of the analysis of variance)

Groups	Score	Sum	Mean	Variance
"Traditional" assessment	40	172	4,3	0,47
Contextual tasks	40	107	2,675	0,37
Test	40	127	3,175	0,35

Table 12 shows the statistical criteria for three different assessment methods: traditional assessment, contextual tasks, and tests. The mean values indicate that the traditional assessment had the highest Mean score (4.30), followed by tests (3.18), and contextual tasks (2.68). The variance values suggest that the scores from traditional assessments and tests were relatively consistent, while the scores from contextual tasks showed more variability.

Table 13

Statistical criteria for the measurement and assessment of the chemical competencies of 11th-grade students (based on the results of the analysis of variance)

Source of Variation	SS	df	MS	F	*p*-value	F-critical
Between Groups	55.42	2	27.71	69.05	1.57E-20	3.07
Within Groups	46.95	117	0.40			
Total	102.37	119				

Table 13 presents the analysis of variance (ANOVA) for the three groups. The F-value (69.05) and the p-value (1.57E-20) indicate that there are significant differences between the groups. The F-critical value (3.07) is lower than the F-value, confirming the significance of the results. This implies that the traditional assessment, contextual tasks, and tests measure different aspects of chemical competencies.

Table 14

Pairwise pearson correlation coefficients between assessment methods

Assessment Method	Traditional Assessment	Contextual Tasks	Test
Traditional Assessment	1	0.48	0.43
Contextual Tasks		1	0.65
Test			1

Table 14 shows the Pearson correlation coefficients between the different assessment methods. The correlation between traditional assessment and contextual tasks is 0.48, indicating a weak relationship. The correlation between traditional assessment and tests is 0.43, also indicating a weak relationship. The correlation between contextual tasks and tests is 0.65, indicating a moderate relationship. These results suggest that the different assessment methods evaluate distinct components of chemical competencies.

Table 15

Statistical criteria for measuring and assessing the chemical competencies of 11th-grade students (based on the results of the analysis of variance)

Group	N	Sum	Mean	Variance
Traditional Assessment	21	80	3.81	0.56
Contextual Tasks	21	54	2.57	0.26
Test	21	60	2.86	0.13

Table 15 presents the mean values show that traditional assessment scores are the highest (3.81), followed by test scores (2.86) and contextual tasks (2.57). The variance indicates that contextual tasks have the least variability in scores (0.26), suggesting consistency in student performance on these tasks.

Table 16

Statistical criteria for measuring and assessing the chemical competencies of 11th-grade students at Gymnasium №178 (based on the results of the analysis of variance)

Source of Variation	SS	df	MS	F	*p*-value	F-critical
Between Groups	17.65	2	8.83	27.94	2.66E-09	3.15
Within Groups	18.95	60	0.32			
Total	36.60	62				

Table 16 provides the ANOVA results for Gymnasium №178. The F-value (27.94) and the very low p-value (2.66E-09) indicate significant differences between the groups. The F-critical value (3.15) being lower than the F-value supports this significance, showing that the traditional assessment, contextual tasks, and tests measure different dimensions of chemical competencies.

Table 17

Pairwise pearson correlation coefficients between assessment methods at gymnasium 178

	Traditional assessment	Contextual tasks	Test
"Traditional" assessment	1		
Contextual tasks	0,82	1	
Test	0,45	0 0,47	1

Table 17 displays the Pearson correlation coefficients between the assessment methods at Gymnasium №178. The correlation between traditional assessment and contextual tasks is 0.83, indicating a strong relationship. The correlation between traditional assessment and tests is 0.45, indicating a weak relationship. The correlation between contextual tasks and tests is 0.47, indicating a weak relationship. These results highlight the significant overlap between traditional assessment and contextual tasks but suggest that tests measure different aspects of competencies.

In the experimental group at Lyceum No. 12 in Almaty, we pairwise compared the results of control using conventional methods and means with the results of UNT. The statistical criteria for analyzing the obtained data are presented in Tables 18 and 19.

Table 18

Statistical criteria for evaluating the chemical competencies of 11th-grade students at Lyceum №12

Groups	*Score*	*Sum*	*Mean*	*Variance*
Traditional assessment	19	77	4,05	0,83
Unified National Testing exams	19	67	3,52	0,59
Contextual tasks	19	58	3,05	0,49

Table 18 shows the statistical criteria for three different assessment methods: traditional assessment, Unified National Testing (UNT), and contextual tasks. The mean values indicate that the traditional assessment had the highest average score (4.05), followed by UNT (3.53), and contextual tasks (3.05). The variance values suggest that traditional assessment scores had the highest variability, followed by UNT and contextual tasks.

Table 19

Analysis of Variance for Evaluating the Chemical Competencies of 11th-Grade Students at Lyceum №12

Analysis of variance						
Source of Variation	SS	df	MS	F	p-value	F-critical
Between Groups	9.51	2	4.75	7.41	0.0014	3.17
Within Groups	34.63	54	0.64			
Total	44.14	56				

Note. The discrepancies in the results are significant at the 0.14% level.

Table 19 presents the analysis of variance (ANOVA) for the three groups. The F-value (7.41) and the p-value (0.0014) indicate significant differences between the groups. The F-critical value (3.17) being lower than the F-value supports this significance, showing that the traditional assessment, UNT, and contextual tasks measure different dimensions of chemical competencies. The discrepancies in the results are significant at the 0.14% level.

Table 20

Pairwise pearson correlation coefficients between assessment methods at lyceum №12

	Traditional methods and means	Unified National Testing (UNT)	Contextual tasks
Traditional methods and means	1		
Unified National Testing (UNT)	0,82	1	
Contextual tasks	0,68	0,66	1

Table 20 displays the Pearson correlation coefficients between the assessment methods at Lyceum №12. The correlation between traditional assessment and UNT is 0.83, indicating a strong relationship. The correlation between traditional assessment and contextual tasks is 0.69, indicating a moderate relationship. The correlation between UNT and contextual tasks is 0.66, also indicating a moderate relationship. These results highlight the significant overlap between traditional assessment and UNT but suggest that contextual tasks measure slightly different aspects of competencies.

Drawing a conclusion about the readiness of a school graduate for life and activity using UNT or through "traditional" control methods is quite challenging. The statistical analysis of the measurement results of the chemical competencies across all experimental groups has identified significant disparities between assessments conducted using conventional control methods and innovative tools, thereby validating the utility of employing comprehensive evaluation for thoroughness and objectivity in assessment. Throughout the study, it was revealed that chemical competencies are cultivated and progressed in correlation and interdependence with key competencies. Consequently, it is imperative to monitor the formation and advancement of not only subject-specific competencies but also the key competencies of students.

Discussion

The results indicate a weak correlation (r = 0.48) between traditional assessment scores and contextual task performance. Traditional assessment methods, such as standardized tests and written exams, primarily measure students' ability to recall and reproduce knowledge (Biggs, 2003; Black & Wiliam, 1998). This finding aligns with the literature, which highlights the limitations of traditional assessments in capturing higher-order thinking skills, such as application, analysis, and problem-solving (Gulikers, Bastiaens, & Kirschner, 2004). Contextual tasks, on the other hand, require students to apply their knowledge in practical, real-world scenarios, reflecting their ability to engage in independent thinking and problem-solving (Shepard, 2000). The weak correlation underscores the need for integrating diverse assessment methods to provide a comprehensive evaluation of students' competencies. Incorporating contextual tasks into the assessment framework can offer a more authentic measure of students' readiness for real-life challenges and better reflect their practical capabilities (Dochy, Segers, & Sluijsmans, 1999).

The relationship between traditional assessment and competency-oriented testing also showed a weak correlation (r = 0.43), suggesting that these two methods evaluate different aspects of student learning. Competency-oriented tests are designed to measure not only the knowledge component but also the skills and attitudes necessary for effective performance in specific contexts (Mulder, Weigel, & Collins, 2007). This approach aligns with the competency-based education framework, which emphasizes the development of holistic competencies rather than isolated knowledge components (Gonczi, 1994). Studies by Shavelson et al. (2008) support the notion that competency-oriented assessments provide a more comprehensive evaluation of student capabilities. The weak correlation found in this study highlights the limitations of traditional assessments in capturing the full range of student competencies. Incorporating competency-oriented testing can help bridge this gap, offering a more nuanced understanding of student learning and performance, and ensuring that students are better prepared for professional and real-life situations.

The moderate correlation (r = 0.65) between contextual tasks and competency-oriented testing suggests that these methods share some commonalities in what they assess. Both approaches aim to evaluate students' ability to apply their knowledge and skills in practical, real-world scenarios (Gulikers et al., 2004). This finding is consistent with the literature, which indicates that contextual and competency-based assessments are more aligned with constructivist learning theories that emphasize active, context-based learning (Jonassen, 1991; Wiggins, 1998). For instance, Gulikers, Bastiaens, and Kirschner (2006) argue that authentic assessments, such as contextual tasks and competency-based tests, provide a more accurate reflection of students' capabilities by situating the assessment in real-life contexts. The moderate correlation observed in this study reinforces the value of these assessment methods in providing a holistic evaluation of student competencies, suggesting that they can effectively complement traditional assessments by capturing a broader range of student skills and knowledge.

A strong correlation (r = 0.83) was observed between traditional assessment results and UNT scores, indicating that both methods largely measure similar aspects of student knowledge. This finding aligns with previous research, which shows that standardized tests, like the UNT, are effective in assessing students' knowledge and understanding of subject content (Popham, 2001). However, these assessments often fall short in evaluating higher-order thinking skills and practical application of knowledge (Resnick & Resnick, 1992). The strong correlation suggests that traditional assessments and UNT are reliable in measuring students' theoretical understanding but may not fully capture their practical competencies. This highlights the need for supplementary assessment methods, such as contextual tasks, to provide a more comprehensive evaluation of student learning and readiness for real-world challenges. The findings suggest that while UNT and traditional assessments are valuable for evaluating knowledge retention, they should be supplemented with methods that assess practical skills and problem-solving abilities.

The statistical analysis revealed significant discrepancies between the results of traditional assessments, contextual tasks, and competency-oriented tests (Tables 4-8). This finding is consistent with the literature, which indicates that different assessment methods measure distinct dimensions of student learning (Biggs, 2003; Shepard, 2000). Traditional assessments are often criticized for their focus on rote learning and recall, whereas contextual tasks and competency-based tests emphasize practical application and critical thinking (Brown, Collins, & Duguid, 1989; Wiggins, 1998). These discrepancies underscore the importance of using a variety of assessment methods to capture a comprehensive picture of student competencies. As noted by Darling-Hammond (2006), a balanced assessment system that includes both traditional and innovative methods can provide a more accurate and complete evaluation of student learning, ultimately leading to better educational outcomes. The significant differences in assessment results highlight the need for educational practices to evolve, incorporating a mix of assessment types to fully understand and support student development.

The findings of this study have important implications for pedagogical practices. The weak correlations between traditional assessments and other methods highlight the limitations of relying solely on conventional assessment techniques. Educators should consider integrating more contextual and competency-based assessments into their teaching practices to better evaluate and support student learning (Gulikers et al., 2004). This approach aligns with the shift towards competency-based education, which emphasizes the development of a broad range of skills and knowledge necessary for success in the 21st century (Voogt & Roblin, 2012). By adopting a more comprehensive assessment strategy, educators can provide students with a more meaningful and relevant learning experience, better preparing them for future challenges. This study reinforces the importance of pedagogical adaptability and the integration of diverse assessment methods to foster a more holistic and practical learning environment.

Conclusion

As a result of the research work, it was found that teachers of natural sciences (biology, geography, chemistry) have the skills to establish patterns and identify cause-and-effect relationships between the components of nature, society and the economy. Therefore, as specialists with broad professional competencies in the field of worldview sciences, they are the most prepared to form the foundations of socio-humanitarian safety among students.

In order to determine the place and role of components of socio-humanitarian safety in natural science education, the features of their implementation in the curricula of institutions of general secondary education are considered. The implementation of components of socio-humanitarian safety within the framework of academic subjects of the natural science cycle has its own distinctive features depending on the subject and the specifics of its teaching methodology.

When developing the conceptual foundations for the training of teachers of natural sciences to implement a competence-based approach in the aspect of socio-humanitarian safety of man and society, methodological approaches are highlighted: competence-based, practice-oriented, system-structural, personal-activity, cultural, integrative. In order to implement these approaches, the application of didactic principles for the selection and design of educational content focused on the formation of socio-humanitarian literacy is justified.

The theoretical model of training future teachers of natural sciences to implement issues of socio-humanitarian safety, represents a system of interrelated structural and functional components: targeted, content-methodological, procedural-activity and performance-evaluation. When developing the model, the moderator identified a competence-based approach that allows students to form all groups of professionally significant competencies.

The main educational programs in chemical disciplines do not emphasize the task of implementing components of socio-humanitarian safety in the training of future teachers of natural sciences. When updating the content of the subjects taught, one of the basic principles at the pedagogical university is the continuity and consistency of university and school programs.

From the point of view of achieving optimal results in preparing future teachers of natural sciences to implement aspects of socio-humanitarian safety, it is necessary to use such methods and forms of work that will contribute not only to more effective assimilation of knowledge, but also allow future teachers to acquire practical skills to apply the acquired knowledge in their future professional activities. The choice of the organizational form of training depends on the conformity of the forms of training sessions with the goals, content and applied teaching methods. When preparing future teachers of biology, geography and chemistry to implement aspects of socio-humanitarian safety in the educational process, it is advisable to introduce interactive learning methods that are aimed at increasing the level of professional competence of the teacher.

To prepare future teachers of the specialty chemistry for the implementation of aspects of socio-humanitarian safety, optional classes "Aspects of socio-humanitarian safety in the study of chemistry in institutions of general secondary education" can become an effective form of work. The content of the offered elective classes is based on the curricula of institutions of higher education in the academic disciplines of the natural science cycle, on methods of teaching chemistry, as well as on curricula in the academic subjects "Chemistry" for institutions of general secondary education.

In conclusion, this study highlights the necessity for integrating diverse assessment methods to capture the full range of student competencies. Traditional assessments, while reliable for measuring theoretical knowledge, fall short in evaluating practical application and higher-order thinking skills. Contextual tasks and competency-oriented tests provide a more holistic assessment, better reflecting students' real-world capabilities. The significant discrepancies between these methods underscore the importance of a balanced assessment approach. Integrating various assessment techniques can provide a more comprehensive evaluation of student learning, ultimately leading to improved educational practices and outcomes. The study's findings suggest that educational systems should move towards incorporating a mix of assessment methods to ensure that all aspects of student competencies are accurately measured and developed.

The implications of this research extend to educational policy and curriculum design, advocating for a more nuanced and multifaceted approach to student assessment. Future research should explore the implementation of these diverse assessment methods across different educational contexts and subject areas to validate and refine the findings of this study. Additionally, professional development for educators should include training on the design and use of contextual and competency-based assessments to ensure effective integration into teaching practices. By adopting a more comprehensive and integrated assessment strategy, educators can better prepare students for the complexities and demands of the modern world.

Author Contributions

Conceptualization, NG; methodology, VAh and ZhM; data curation, NG and NZh; writing – original draft preparation, NG, VAh and MO; writing – review and editing, MO; visualization, ZhM and NZh; supervision, VAh. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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Science lesson-focused responsibility levels of primary school pupils

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** This article draws on the first author's Master's thesis parts written by the 1st author's master thesis entitled "Developing Science Lesson-Focused Student Responsibility Scale and Determining Primary School Students' Responsibility Levels", conducted under the supervision of the 2nd author.*

ABSTRACT
The study aimed to determine science lesson-focused responsibility levels of primary school students in terms of various demographic variables. This study used a quantitative research methodology and a descriptive survey model, one of the general survey models. The research was conducted in three central districts in Kayseri province, Türkiye, in the 2018-2019 academic year. The research sample included 705 pupils. The study collected data through the "Science Lesson-Focused Pupil Responsibility Scale" developed by the researchers. Scales' Cronbach Alpha internal consistency coefficient is .87 and the scale explains 50.83% of the total variance. Results of the study revealed that the children's science lesson-focused responsibility levels differed significantly in favour of female students (U=53495.5; p<0.05). Furthermore, lesson-focused responsibility levels differed significantly in favour of third-grade pupils. They differed significantly in favour of "those who like the lesson very much" according to interest level in the science lesson (U = 43331.0; p <0.05). However, they did not vary by birth order ($X^2_{(3)}$ =.236; p> 0.05), the number of siblings ($X^2_{(3)}$ = 1.140; p>.05), preschool experience (U = 24494.0; p>0.05), or the educational level of parents (U = 24494.0; p>0.05). Based on the results, boys can be assigned tasks in which they can take responsibility within the scope of daily life and science lessons, and studies that increase their level of responsibility can be carried out. In addition, the contents of the science course curriculum and textbooks can be enriched by including activities based on practices that increase learner curiosity and interest levels.

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Introduction

The development of a society and its ability to solve its economic and social problems depends on its science, technology and innovation capabilities. These abilities are vital in determining the society's development and economic growth rate (Juma et al., 2005, p.20). For this reason, these abilities should be inculcated in individuals (Rhodes & Sulston, 2010). Science education is vital in providing individuals with skills for science, technology and innovation. The science education curriculum aims to train individuals for a sustainable environment, economy and society, following scientific and technological developments and seeking and producing solutions to socio-scientific problems.

Responsibility is making choices about one's behaviour and accepting the effects and consequences of those choices (Gliker, 1970; Popkin, 1987). These choices are primarily made to meet an individual's physiological, safety and social needs. Social needs, which include belonging, being accepted and liked, social life enable the individual to interact with others and become a member of society (Maslow, 1970). Social life directs the individual to undertake various duties to protect the peace and security of their environment. This is because of a sense of responsibility.

Responsibility contributes to individuals self-awareness, acquiring a healthy sense of self by recognising their competencies and limitations, and directing their lives accordingly. Individuals with a sense of responsibility respect differences by accepting that everyone in society is valuable and has unique differences (Cüceloğlu, 2017; Glasser, 2005; Wubbolding, 2015). They feel responsible for their environment and society and are willing to undertake various duties. They like and feel attached to the earth, respect all living and non-living beings and pay attention to protecting nature. This stance makes responsible individuals more honest, conscientiousness, reliable and respected in society (Douglass, 2001; Ergül & Kurtulmuş, 2014; Gough et al., 1952; Karagöz, 2013; Messina, 2004; Spielmann et al., 2022).

In the literature, responsibility is defined into two categories individual and social. Individual responsibility is an individual's choice-making for their own life and accepting possible negative consequences (Burke et al., 2001; Glasser, 2005; Romi et al., 2009; Ryan & Bohlin, 1999). On the other hand, social responsibility is defined as the individual's actions for the benefit of society, without pursuing a relationship based on their interest, due to their sense of belonging in the social order (Berkowitz & Lutterman, 1968; Özen, 2015).

Responsibility is an essential consciousness for social peace and prosperity. Responsibility is essential for harmony in many social environments, such as family, school, and business. Unfortunately, many political, military, economic, and ecological problems are caused by individuals and institutions not fulfilling their responsibilities in the right way and at the right time (Taylı, 2013; Yeşil, 2015; Yontar, 2007).

COVID-19, a recent example of a significant pandemic that shaped world history, is a concrete example of the importance of responsibility in this context. According to information from the World Health Organization (WHO, 2020), the scientific world was confronted with a new type of coronavirus after the emergence of pneumonia cases of unknown origin in Wuhan, Hubei province, the People's Republic of China, on December 31, 2019. The virus was identified as SARS-CoV-2, causing COVID-19, on January 7, 2020, and a pandemic was later declared (WHO, 2020; Dindar Demiray & Alkan Çeviker, 2020, Ortuzar-Iragorri et al., 2024). Since COVID-19 is a type of virus, it survives in living organisms. Therefore, the virus not only affects the infected individual but also affects those in close contact with these individuals.

For this reason, in every country, necessary institutions made serious announcements about the use of masks, distancing, and hygiene to prevent the spread of the virus. In combating the pandemic, individuals must undertake the necessary responsibilities for their health and the protection of public health (Çobanoğlu, 2020). As a result, responsibility education effectively raises individuals who can cope with individual and social problems (Glasser, 2016; Gündüz, 2014; Kısa, 2009).

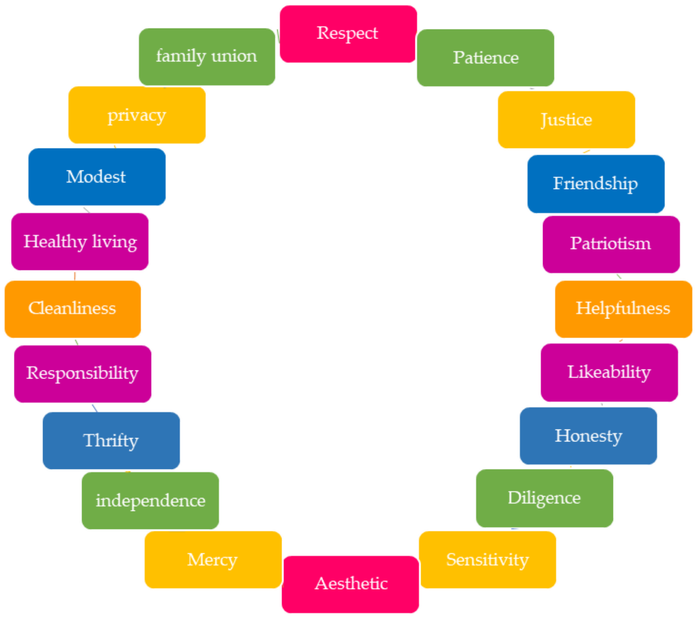
In early childhood, responsibility begins to develop from personal responsibility to social responsibility (Hayta Önal, 2005, p.1). For this reason, individuals should take responsibilities appropriate to their age, developmental level, and gender in childhood (Yavuzer, 1996, p. 107). Based on " bend a tree while it is young," individuals must gain a sense of responsibility from early childhood, transforming knowledge into action. To develop responsibility, individuals should grow up in environments where they can take responsibility. In addition, they should be allowed to make choices and take responsibility for the consequences of these choices. Otherwise, a sense of responsibility is unlikely to develop (Cüceloğlu, 2017). Many factors affect the development of responsibility. Family structure, socioeconomic status, school life and social environment are significant factors (Cüceloğlu, 2017; Glasser, 2018).

Educational institutions are organizations that hold direct responsibility and instil a sense of responsibility through their function (Demirci Güler & Açıkgöz, 2019). According to Yavuzer (2006, p. 147), "In modern education, a school is the only social institution that takes the responsibility of teaching certain knowledge patterns and skills and attitudes." Schools contribute to the personal learning of basic knowledge, skills, and values and the individual's self-realisation by meeting their academic and psychological needs. In this respect, schools contribute to the integration of the individual into society and raise them as individuals who will advance society to further (Aslan, 2011; Maslow, 1954; Rothstein, 2000).

The general objectives of the Turkish National Education System are that “All members of the Turkish nation who are of a moderate and healthy personality and mentality and character in terms of physically, mentally, morally, spiritually and emotionally the power of free and scientific thinking, a comprehensive worldview, be respectful of human rights, appreciate enterprise and individuality, who feel a responsibility towards society" (Basic Law of National Education, 1973, p.5101). For this purpose, values education is incorporated into the curricula of our country in the form of "values and competencies" across all educational programs. Furthermore, responsibility is also one of the mentioned root values targeted for acquirement in this context (Ministry of National Education, 2024). Figure 1 shows the twenty root values in the curriculum for science lessons.

Figure 1

Root values in the curriculum for the 2024 science course



Relationship Between Science Education and Responsibility

According to Francis Bacon's famous phrase, "Knowledge is power." regarding this expression, the basic principle for developed and developing countries to achieve global economic power and success is to be a society that acquires scientific knowledge and expands it (Çepni et al., 1997; Özmehmet, 2008). This fact increases the importance of educational activities in raising a qualified workforce (Buyruk, 2016). Science education is the process of individuals learning to explain, interpret and discover natural phenomena encountered in daily life by using scientific ideas and acquiring science process skills (Asoko, 2002, p. 153; Yıldız Taşdemir & Güler Yıldız, 2024). Science education plays an active role in that individuals shape the future of their country and affect the world economy. The welfare of societies depends on the sustainability of science and technological developments. Such that countries with the highest success rate in the Trends in International Mathematics and Science Studies Research (TIMSS, 2019) and the International Student Assessment Program (PISA, 2018) are also countries with a high level of development. These countries' education systems tend to have a comprehensive and thorough science education component. The science education programmes of some countries with high scores in PISA 2018 and TIMSS 2019 are briefly evaluated below.

In the Finnish science curriculum, research- and problem-based approaches and focus on applied education were adopted by limiting the number of acquirements and aiming to raise pupils as individuals who are more sensitive to health and social issues (Özcan & Gücüm, 2020; Finnish National Agency for Education, 2020).

The basic philosophy of the Canadian science curriculum is that learners ought understand the nature and value of science and acquire scientific process skills. In this context, scientific process skills were combined with various subject titles and presented integrated with subjects. The curriculum aims to enable students to contribute to their daily lives, career development, and science with these outcomes (Bakaç, 2014; Ontario Ministry of Education, 2007).

The aim of the Hong Kong science curriculum is that students develop a positive attitude towards science, learn the language of science, and cultivate individuals who respect living and non-living beings, which are elements of the ecosystem (Cangüven et al., 2017; Hong Kong/Education Bureau, 2017).

The Estonian science curriculum aims to raise responsible individuals who understand the value of science and can generate ideas about socio-scientific issues, seek solutions to the problems they encounter by learning scientific process skills, and adopt a sustainable lifestyle. Compared with Turkey, starting to teach science in the first grade of primary schooling is a striking point. However, there are few outcomes in the curriculum. Therefore, the curriculum focuses on increasing the course quality (Republic of Estonia/Ministry of Education and Research, 2014; Karaer, 2016).

The programmes of these prosperous countries aim for school learners to realise the value of science, take responsibility for both personal and social life, and contribute to science in their future lives. The programmes are supported by practical educational activities aimed at this target. The main point of achieving this goal is to "raise science-literate individuals." The main goal of the curricula in these countries is to raise responsible and effective citizens who can achieve the countries' development goals by attaining academic success including in science.

Responsibility is one of the significant variables for academic success. Many studies accept that it is a motivating factor for student success. These studies indicate that individuals with a high sense of responsibility have advanced self-organising skills and high academic success (Aladağ, 2009; Brecke & Jensen, 2007; Helker & Wosnitza, 2016; Macready, 2009; Martel, McKelvie & Standing, 1987; Pomerantz et al., 2011; Wentzel, 1991)

There is a parallel relationship between the level of development of countries and education quality. For this reason, science education is essential for training responsible individuals who produced science and technology. (Ayas, 1995; Çepni et al., 2003; Matthews, 2017). In this context, understanding the role of responsibility in science education becomes crucial. For this reason, we examined studies about responsibility and responsibility education in the literature. We found that studies are in the psychology-psychological counseling and guidance field (Anderson, 2000; Dilmaç, 2007; Hayta Önal, 2005; Ryan & Deci, 2000) and social studies and life field (Aladağ, 2009; Gündüz, 2014; Kılcan, 2013; Sezer, 2008; Tepecik, 2008).

These studies primarily focus on student and teacher perspectives (Akbaş, 2004; Aydoğan & Gündoğdu, 2015; Burke et al., 2001; Helker & Wosnitza, 2016; Kaplan & Sulak, 2017; Kısa, 2009; Li et al., 2008; Sağlam & Kaplancı, 2018; Sapsağlam, 2017; Sezer & Çoban, 2016; Such & Walker, 2004; Şahan, 2011; Yontar, 2013). In the field of science, studies related to responsibility and value teaching are limited and include research by Çepni et al. (2003), Fuchs and Tan (2022), Kunduroğlu (2010), Tahiroğlu et al. (2010), Ayas et al. (2013), Küçükaydın (2015), Chowdhury (2016), Herdem (2016), Tekbıyık and Akdeniz (2017), and Yakar (2017).

These studies did not address the association between science lessons and responsibility. Therefore, we identified a need for research on the relationship between responsibility and science and decided to conduct this study. In this context, we aimed to contribute to the literature through this research.

This study aimed to examine the science lesson-focused responsibility levels of primary school third and fourth-grade pupils in terms of various demographic variables and to solve the following sub-problems.

1. What is the responsibility level of primary school third and fourth-grade pupils focused on science lessons?
2. Do third and fourth-grade pupils' responsibility levels focused on science lessons differ significantly based on gender, grade level, preschool experience, number of siblings, birth order, parental educational attainment, and interest in science lessons?

Methods

The study aimed to determine primary school third and fourth-grade pupils' science lesson-focused responsibility levels with reference to various demographic variables (class, gender, number of siblings, birth order, preschool experience, parental education status, and level of interest in science lesson). A descriptive research model is used in this study. The descriptive research model is a research model in which the researcher aims to determine the current state without changing the past or present situation, event, individual or object (Karasar, 2016). This model is used in studies that describe the current situation one by one and in detail in terms of variables or components encountered in nature (Karasar, 2016).

Population and Sample

The population of this research was defined as primary school third and fourth-grade students in Kayseri during the 2018-2019 academic year. The research sample consisted of 705 third and fourth-grade pupils from three central districts of Kayseri in the autumn semester of the 2018-2019 academic year. The sample was selected using the typical case sampling method. According to Büyüköztürk et al. (2018, p.94), "The typical case sampling method involves collecting information from a sample by identifying a situation that is representative of many similar situations in the population, related to the research topic". The study examined the science lesson-focused responsibility levels of primary school students based on various demographic characteristics. Demographic information and the students' interest in science lessons are provided in Table 1.

Table 1

Demographic characteristics of the sample group

Variable	Group	n	%
	Girl	330	46.8
Gender	Boy	375	53.2
	Total	705	100
	3rd Grade	363	51.5
Grade	4th Grade	342	48.5
	Total	705	100
	Only child	52	7.4
	2 siblings	371	52.6
Number of siblings	3 siblings	212	30.1
	4 siblings or more	70	9.9
	Total	705	100

Birth order	1st	304	43.1
	2nd	276	39.1
	3rd	90	12.8
	4th or higher	35	5.0
	Total	705	100
Preschool experience	Experienced	618	87.7
	Did not experience	87	12.3
	Total	705	100
Maternal education level	University	164	23.3
	Upper secondary	142	20.1
	Lower secondary school	152	21.6
	Primary school	229	32.5
	Illiterate	18	2.6
	Total	705	100
Paternal education level	University	175	24.8
	Upper secondary	121	17.2
	Lower secondary school	130	18.4
	Primary school	223	31.6
	Illiterate	56	7.9
	Total	705	100
Interest in science lesson	I do not like it	35	5.0
	I like it a little	38	5.4
	I like it	632	89.6
	Total	705	100

The number of primary school third and fourth-grade students attending education in the city of Kayseri, which constitutes the population of the study, in the 2018-2019 academic year was obtained from the data system of the Ministry of Education, Department of Strategy Development. The relationship with the sample size was examined (Ministry of Education, Department of Strategy Development, 2019). In this context, the data about the research population and sample are given in Table 2.

Table 2

Research population and samples

Grade	Population	Samples
3rd grade	23 665	363
4th grade	22 906	342
Total	46 571	705

Table 2 shows that there was a total of 46 571 students at the 3rd and 4th-grade level in Kayseri in the 2018-2019 academic year. 23 665 students were in the 3rd grade, and 22,906 were in the 4th grade in primary school. The number of students in the sample group for the application phase of the study shows that 363 were in the 3rd grade and 342 were in the 4th grade, with a total of 705 students participating in the sample. According to the relationship between population and sample numbers, the total number of students included in the sample is close to the 95% confidence interval accepted for a population with approximately 20,000 participants according to the .05-significance level (Cohen et al., 2007). In this context, it may say that the sample size is sufficient.

Data Collection Tools

The data were collected with the use of the personal information form and the "Science Lesson-Focused Student Responsibility Scale" developed by the researcher (Açıkgöz & Demirci Güler, 2021).

Personal Information Form

With the personal information form, information about gender, grade level, number of siblings, birth order, preschool experience, parents' education status, and science course interest levels were collected.

Science Lesson-Focused Student Responsibility Scale

The scale developed by researchers aimed to determine the science course-focused responsibility levels of the children (Author[1] & Author[2], 2021). In scale development, the sample consisted of 870 students. For the scope validity of the items, 11 experts' opinions were consulted. The content validity ratios of each item were calculated according to the Lawshe technique (Lawshe, 1975). For construct validity, exploratory factor analysis and confirmatory factor analysis were used.

As a result of the analysis, a Likert-type scale was developed with 17 items and with four factors. These four factors are "conscious resource consumption", "health awareness", "safety awareness" and "environmental awareness".

Scales' Cronbach Alpha internal consistency coefficient is .87, and the scale explains 50.83% of the total variance.

Data Collection

In this study, we decided to use a descriptive survey model. Firstly, we researched studies about the relationship between responsibility and science lessons in literature. We noticed that responsibility is an essential value for the science lesson. And we set two research problems. Then, we used a data collection tool and personal information form, which we developed, to answer the research problems. We obtained permission from the education authorities to carry out the research at primary schools. We collected data from 705 third and fourth-grade students in 3 central districts of Kayseri city in the fall semester of the 2018-2019 academic year.

Data Analysis

We tested the normality of data for demographic features and student responsibility levels. As a result of the normality tests for each sub-problem, we did not determine normal distribution ($p>.05$). For this reason, we tested the Mann-Whitney U test, which is one of the non-parametric tests for binary relationship, and the Kruskal-Wallis H test for two or more relationship. We examined the hypothesis test of the Kruskal-Wallis H test for relationship with significant differences (Büyüköztürk, 2018; Can, 2017).

The score ranges for the data collection tool were calculated using the n-1/n(n= Likert number) formula to determine the level of responsibility of pupils focused on the science lesson. Since the scale has 3 items and 2 even intervals, a value of 2/3 = 0.66 was obtained. Likert levels obtained according to the score ranges are never = 1 point (1.00-1.66), sometimes = 2 points (1.67-2.33), and always = 3 points (2.34-3.00).

The validity-reliability analysis of the data collection tool and analysis of data from the implementation phase was carried out using IBM SPSS Statistics 25 package programs.

Results

In this section, information about students' science lesson-focused responsibility levels regarding various demographic variables is presented. The science-focused responsibility level scores are shown in Table 3.

Table 3

Science lesson-focused responsibility level of primary school 3rd and 4th grade pupils

Factor	f	$\bar{X}$	sd
Science lesson-focused student responsibility scale	705	2.64	.32
➢ Conscious resource consumption	705	2.61	.44
➢ Safety awareness	705	2.78	.31
➢ Health awareness	705	2.59	.42
➢ Environment awareness	705	2.60	.40

Table 3 shows that the arithmetic means of pupils' responsibility level is 2.64. Students' responsibility level in the safety awareness factor is the highest ($\bar{X}$=2.78), and responsibility in the health awareness factor is the lowest ($\bar{X}$=2.59). According to the information obtained, pupils' responsibility levels are in the high-level range for the overall scale and each sub-factor ($2.34<\bar{X}<3.00$).

We examined the relationship between gender and pupils' responsibility level, shown in Table 4.

Table 4

Science lesson-focused responsibility levels of primary school 3rd and 4th grade students according to gender

Group	f	Average rank	Rank sum	U	p
Girl	330	378.39	124869.5	53495.5	.002
Boy	375	330.65	123995.5		

Table 4 shows there is a significant difference between the science lesson-focused responsibility levels of girls and boys (U=53495.5; $p<0.05$). By Average ranks, the science-focused responsibility levels of girls (X=378,39) were higher than those of boys (X=330.65).

We examined the relationship between responsibility sub-factor levels and gender, shown in Table 5.

Table 5

Mann-Whitney U Test results of science lesson-focused responsibility level sub-factors according to gender

Factors	Gender	f	Average rank	Rank sum	U	p
Conscious resource consumption	Girl	330	368.20	121507.00	56858.000	.055
	Boy	375	339.62	127358.00		
Safety awareness	Girl	330	361.82	119400.50	58964.500	.242
	Boy	375	345.24	129464.50		
Health awareness	Girl	330	388.21	128109.00	50256.000	.000
	Boy	375	322.02	120756.00		
Environment awareness	Girl	330	371.50	122595.00	55770.000	.021
	Boy	375	336.72	126270.00		

Table 5 shows that in the sub-factors of "conscious resource consumption" (U= 56858.0; p>0.05) and "safety awareness" (U= 58964.5; p>.05), there is not a significant difference between the responsibility levels of girls and boys. There is a statistically significant difference in favour of girls students for the sub-factors of "health awareness" (U= 50256.0; p<.05) and "environmental consciousness" (U= 55770.000; p<0.05). These results show that the "health awareness" (X=388.21) and "environmental awareness" (X=371.50) responsibility levels of girls are higher than the "health awareness" (X=322.02) and "environmental awareness" (x=336.72) responsibility levels of boys.

We examined the relationship between responsibility level and grade levels, shown in Table 6.

Table 6

Mann-Whitney U Test results for science-focused responsibility levels of primary school 3rd and 4th grade Students

Grade	f	Average rank	Rank sum	U	p
3rd	63	404.63	146881.00	43331.000	000
4th	42	298.20	101984.00		

Table 6 shows that there is a statistically significant differences between the responsibility levels and grade level (U = 43331.0; p <0.05). According to the Average ranks, the responsibility levels of third-grade pupils (X=404.63) are higher than the fourth-graders (X=298.20).

We examined the relationship between responsibility sub-factor levels and grade levels, shown in Table 7.

Table 7

Mann-Whitney U Test results of science lesson-focused responsibility level sub-factors according to grade level

Sub-factors	Grade	f	Average rank	Rank sum	U	p
Conscious resource consumption	3	363	396.09	143781.50	46430.500	.000
	4	342	307.26	105083.50		
Safety awareness	3	363	389.61	141430.00	48782.000	.000
	4	342	314.14	107435.00		
Health awareness	3	363	378.80	137504.00	52708.000	.000
	4	342	325.62	111361.00		
Environment awareness	3	363	393.01	142662.00	47550.000	.000
	4	342	310.54	106203.00		

Table 7 shows that there is a statistically significant differences in favour of third-grades in the responsibility sub-factors of "conscious resource consumption" (U= 46430.5; p<0.05), "safety awareness" (U= 48782.0; p<0.05), "health awareness" (U= 52708.0; p<0.05) and "environmental awareness" (U=47550.0; p<0.05). These results show that the "conscious resource consumption", "safety consciousness", "health awareness" and "environmental awareness" responsibility levels of third-grade pupils are higher than the responsibility levels of fourth-grade pupils.

We examined the relationship between responsibility level and the number of siblings, shown in Table 8.

Table 8

Kruskal Wallis H Test results for science-focused responsibility levels of 3rd and 4th grade students according to number of siblings

Sibling number	f	Average rank	df	X^2	p
Only child	52	348.37			
2	371	347.42	3	1.140	.767
3	212	356.95			
4	70	374.04			

Table 8 shows that there is not a statistically significant difference between responsibility levels and the number of siblings ($X^2_{(3)}$ = 1.140; p>.05). However, as the number of siblings increases the average responsibility scores increase. In this case, as the number of siblings increases, individuals take more responsibility in large families.

The sub-factors of the students' science-focused responsibility levels were examined according to the number of siblings, shown in Table 9.

Table 9

Kruskal Wallis H Test results for science lesson-focused responsibility level sub-factors according to the number of siblings

Sub-factors	Sibling number	f	Average rank	df	x^2	p
Conscious resource consumption	Only child	52	340.75			
	2	371	344.65	3	2.274	.518
	3	212	363.74			
	4	70	373.84			
Safety awareness	Only child	52	345.23			
	2	371	352.13	3	.167	.983
	3	212	356.41			
	4	70	353.04			
Health awareness	Only child	52	358.90			
	2	371	349.18	3	.874	.832
	3	212	351.88			
	4	70	372.23			
Environment awareness	Only child	52	336.24			
	2	371	349.15	3	1.951	.583
	3	212	354.43			
	4	70	381.52			

Table 9 shows that there is not a statistically significant differences between the number of siblings and responsibility sub-factors of “conscious resource consumption” ($X^2_{(3)}$ = 2.274; p>0.05), “safety awareness” ($X^2_{(3)}$ = .167; p>0.05), “health consciousness” ($X^2_{(3)}$ = .874; p >0.05) and “environmental awareness” ($X^2_{(3)}$ = 1.951; p>0.05).

We examined the relationship between responsibility level and birth order, shown in Table 10.

Table 10

Kruskal Wallis H Test results for science-focused responsibility levels of 3rd and 4th grade students according to birth order

Birth order	f	Average rank	df	X^2	p
1st child	304	350.13	3	.236	.972
2nd child	276	357.24			
3rd child	90	348.44			
4th child	35	356.27			

Table 10 shows that there is not a statistically significant difference between responsibility levels and birth order ($X^2_{(3)}$ =.236; p> 0.05). This result parallels the relationship between science lesson-focused responsibility level and the number of siblings.

We examined the relationship between responsibility sub-factors levels and birth order, shown in Table 11.

Table 11

Kruskal Wallis H Test results for science lesson-focused responsibility level sub-factors according to birth order

Sub-factors	Birth order	f	Average rank	df	X^2	p
Conscious resource consumption	1st	304	350.14	3	.121	.989
	2nd	276	355.78			
	3rd	90	353.78			
	4th	35	353.97			
Safety awareness	1st	304	362.18	3	2.288	.515
	2nd	276	344.89			
	3rd	90	338.22			
	4th	35	375.17			
Health awareness	1st	304	358.37	3	.783	.854
	2nd	276	352.59			
	3rd	90	343.70			
	4th	35	333.50			
Environment awareness	1st	304	338.54	3	2.959	.398
	2nd	276	363.45			
	3rd	90	360.92			
	4th	35	375.83			

Table 11 shows that there is not a statistically significant differences between the birth order and responsibility sub-factors of "conscious resource consumption" ($X^2_{(3)}$ =.121; p>0.05), "safety awareness" ($X^2_{(3)}$ =2.288; p>0.05), "health awareness" ($X^2_{(3)}$) =.783; p >0.05) and "environmental consciousness" ($X^2_{(3)}$ = 2.959; p>0.05).

We examined the relationship between responsibility level and preschool experience status, shown in Table 12.

Table 12

Mann-Whitney U Test results for science-focused responsibility levels of primary school 3rd and 4th grade students and preschool experience

Group	f	Average rank	Rank sum	U	p
Experienced	618	349.13	215765.00	24494.000	.178
Did not experience	87	380.46	33100.00		

Table 12 shows that there is not a statistically significant difference between responsibility levels and preschool experience ($U = 24494.0$; $p>0.05$). However, according to Average rank, responsibility levels of students who have not preschool experience are had higher than students who have preschool experience.

We examined the relationship between responsibility sub-factors levels and preschool experience, shown in Table 13.

Table 13

Mann Whitney U Test results for science lesson-focused responsibility level sub-factors according to preschool experience

Sub-factors	Group	f	Average rank	Rank Sum	U	p
Conscious resource consumption	Experienced	618	351.76	217385.50	26114.500	.656
	Did not experience	87	361.83	31479.50		
Safety awareness	Experienced	618	351.15	217010.50	25739.500	.486
	Did not experience	87	366.14	31854.50		
Health awareness	Experienced	618	345.02	213223.50	21952.500	.004
	Did not experience	87	409.67	35641.50		
Environment awareness	Experienced	618	349.48	215976.00	24705.000	.211
	Did not atten	87	378.03	32889.00		

Table 13 shows that there is not a statistically significant differences between the preschool experience and responsibility sub-factors of “conscious resource consumption” ($U= 26114.5$; $p>0.05$), “safety awareness” ($U= 25739.5$; $p>0.05$) and “environmental awareness” ($U= 24705.0$; $p>0.05$). However, there is a statistically significant difference between the preschool experience and "health consciousness “sub-factor ($U= 21952.5$; $p<0.05$) in favour of those who have not preschool experience.

We examined the relationship between responsibility level and maternal education status, shown in Table 14.

Table 14

Kruskal Wallis H Test results for science-focused responsibility levels of primary school 3rd and 4th grade pupils and maternal education status

Education status	f	Average rank	df	X^2	p
University	164	346.11	4	4.107	.392
Upper secondary	142	362.62			
Lower secondary school	152	368.42			
Primary school	229	337.35			
Illiterate	18	408.78			

Table 14 shows that there is not a statistically significant difference between responsibility levels and maternal education level ($X^2_{(4)}$ = 4.107; p>0.05). However, according to Average ranks, the responsibility levels of children whose mothers are illiterate are higher than those whose mothers have other educational levels.

We examined the relationship between responsibility sub-factors levels and maternal education level, shown in Table 15.

Table 15

Kruskal Wallis H Test results for science lesson-focused responsibility level sub-factors according to maternal education level

Sub-factor	Education status	f	Average rank	df	X^2	p
Conscious resource consumption	University	164	363.13			
	Upper secondary	142	367.19			
	Lower secondary school	152	358.27	4	6.122	.190
	Primary school	229	329.02			
	Illiterate	18	409.36			
Safety awareness	University	164	337.41			
	Upper secondary	142	353.69			
	Lower secondary school	152	361.32	4	3.804	.433
	Primary school	229	352.86			
	Illiterate	18	421.17			
	University	164	336.72			
Health awareness	Upper secondary	142	354.23			
	Lower secondary school	152	383.10	4	5.915	.206
	Primary school	229	341.65			
	Illiterate	18	381.83			
Environment awareness	University	164	345.09			
	Upper secondary	142	369.74			
	Lower secondary school	152	357.90	4	1.922	.750
	Primary school	229	343.90			
	Illiterate	18	367.28			

Table 15 shows that there is no statistically significant differences between the maternal education levels and responsibility sub-factors of “conscious resource consumption” ($x^2_{(4)}$ = 6.122; p>0.05), “safety awareness” ($x^2_{(4)}$=3.804; p>0.05), “health awareness” ($x^2_{(4)}$= 5.915; p>0.05) and “environmental consciousness” ($x^2_{(4)}$ =1.922; p>0.05).

We examined the relationship between responsibility level and fathers’ education status, shown in Table 16.

Table 16

Kruskal Wallis H Test results for science-focused responsibility levels of primary school 3rd and 4th grade students according to paternal education levels

Education status	f	Average rank	df	X^2	p
University	175	365.51			
Upper secondary	121	352.09			
Lower secondary school	130	343.51	4	1.177	.882
Primary school	223	352.43			
Illiterate	56	340.19			

Table 16 shows that there is not a statistically significant difference between responsibility levels and father education levels ($X^2_{(4)}$ = 1.177; p> 0.05). However, according to average rank, the responsibility levels of students whose fathers with university graduates were higher than those whose fathers with another educational level.

We examined the relationship between responsibility sub-factors levels and fathers' education level, shown in Table 17.

Table 17

Kruskal Wallis H Test results for science lesson-focused responsibility level sub-factors according to paternal education level

Sub-factors	Education status	f	Average rank	df	X^2	p
	University	164	358.95			
Conscious resource consumption	Upper secondary	142	369.47			
	Lower secondary school	152	353.21	4	2.018	.732
	Primary school	229	344.35			
	Illiterate	18	332.78			
	University	164	364.10			
	Upper secondary	142	342.57			
Safety awareness	Lower secondary school	152	337.70	4	2.035	.729
	Primary school	229	358.30			
	Illiterate	18	355.25			
	University	164	370.72			
	Upper secondary	142	347.07			
Health awareness	Lower secondary school	152	353.37	4	2.283	.684
	Primary school	229	346.74			
	Illiterate	18	334.47			
	University	164	359.85			
	Upper secondary	142	349.32			
Environment awareness	Lower secondary school	152	343.29	4	.580	.965
	Primary school	229	354.79			
	Illiterate	18	354.94			

Table 17 shows that there is not a statistically significant differences between the maternal education levels and responsibility sub-factors of "conscious resource consumption" ($x^2_{(4)}$ = 2.018; p>0.05), "safety awareness" $x^2_{(4)}$= 2.035; p>0.05), "health consciousness" ($x^2_{(4)}$= 2.283; p>0.05) and "environmental consciousness" ($x^2_{(4)}$ =580; p>0.05).

We examined the relationship between responsibility level and science lesson interest levels, shown in Table 18.

Table 18

Kruskal Wallis H Test results for science-focused responsibility levels of primary school 3rd and 4th grade students focused on science lesson interest levels

Interest levels	f	Average rank	df	X^2	p	Significant difference
(1) I do not like it	35	174.99				
(2) I like it a little	38	264.75	2	37.640	.000	1-3 2-3
(3) I like it	632	368.16				

Table 18 shows that there is a statistically significant difference between responsibility levels and interest level of science lesson ($X^2_{(2)}$ = 37.640; p<0.05). According to the results of the hypothesis test, the science lesson-focused responsibility levels of the pupils are significantly different in favour of those who "like" the lesson. According to mean rank, as the interest level increases, responsibility level increase.

We examined the relationship between responsibility sub-factors levels and interest level of science lesson, shown in Table 19.

Table 19

Kruskal Wallis H Test results for science lesson-focused responsibility level sub-factors according to interest level of science lesson

Sub-factor	Interest levels	f	Average rank	df	X^2	Kruskal Wallis p	Hypothesis test p	Significant difference
Conscious resource consumption	(1) I do not like it	35	231.09				.960	1-2
	(2) I like it a little	38	277.08	2	21.054	.000	.000	2-3
	(3) I like it	632	364.32				.024	1-3
Safety awareness	(1) I do not like it	35	261.36				1.00	1-2
	(2) I like it a little	38	268.71	2	17.844	.000	.005	2-3
	(3) I like it	632	363.14				.008	1-3
Health awareness	(1) I do not like it	35	247.24				1.00	1-2
	(2) I like it a little	38	287.24	2	16.148	.000	.062	2-3
	(3) I like it	632	362.81				.002	1-3
Environment awareness	(1) I do not like it	35	186.37				.108	1-2
	(2) I like it a little	38	284.29	2	31.823	.000	.000	2-3
	(3) I like it	632	366.36				.041	1-3

Table 19 shows that there were statistically significant differences present. For the "Conscious Resource Consumption" sub-factor, there is a statistically significant difference between those who "disliked" the science lesson and those who "liked it", and between those who "liked it a little" and "like it" in favour of those who "liked" the lesson ($X^2_{(2)}$= 21,054; p<0.05). For the "Safety Awareness" sub-factor, there is a statistically significant difference between those who "disliked" and "liked" the science lesson, and "somewhat liked" and "liked" in favour of those who "liked" the lesson ($X^2_{(2)}$= 17,844; p<0.05). There was a statistically significant difference in favour of those who "liked" the lesson ($X^2_{(2)}$= 16,148; p<0.05) between those who "disliked" the science lesson and those who "liked it" for the "Health Consciousness" sub-factor. For the "Environmental Awareness" sub-factor, there is a statistically significant difference ($X^2_{(2)}$= 31,823; $p<0.05$) between those who "liked" the lesson and "those who liked it a little" and those who "liked it a little" in favour of those who "liked" the lesson.

Discussion and Conclusion

This study aimed to determine the science lesson-focused responsibility levels of primary school 3rd and 4th-grade pupils in relation to various demographic variables. The results are discussed in light of the existing literature.

We calculated the arithmetic mean value for the science lesson-focused responsibility level of the children. This value was 2.64. This indicates a high level of responsibility ($2.34<\bar{X}<3.00$). The arithmetic mean scores for the sub-factors of responsibility levels were also examined. We found that the 'Safety Awareness' factor had the highest score (2.78), while the 'Health Awareness' factor had the lowest score (2.59). However, the responsibility scores for both sub-factors were within the range of 2.34 to 3.00, indicating high responsibility levels.

We analyzed the association between gender and responsibility levels and found that the responsibility levels of girls were higher than those of boys. Many studies in the literature on responsibility and gender have similarly reported that the responsibility levels of female participants (particularly adult females) were higher than those of males (Akbaş, 2004; Berkowitz & Lutterman, 1968; Golzar, 2006; Demirhan İşcan, 2007; Kraft & Singhapakdi, 1995, p. 321; Sağlam & Kaplancı, 2020; Şahan, 2011). Additionally, we examined the association between gender and the sub-factors of responsibility levels related to science courses. Our analysis revealed no significant difference between girls and boys for the sub-factors of "Conscious Resource Consumption" and "Safety Awareness." However, there was a statistically significant difference in favor of girls for the sub-factors "Health Consciousness" and "Environmental Consciousness." These results indicate that girls exhibited significantly higher responsibility levels than boys in terms of "Health Awareness" and "Environmental Awareness." In this context, our findings align with much of the research in the literature. However, our results differ from those of Güdürü (2021) and Özcan (2021), who found no significant relationship between responsibility levels and gender.

We analysed the relationship between students' grade levels and science lesson-focused responsibility levels. We found that the responsibility levels of the 3rd-grade pupils were higher than the 4th-graders. We examined the association between grade levels and responsibility level sub-factors. We found that there was a statistically significant difference in favour of third-graders for all sub-factors of the scale. Piaget suggested that range of 6-10 years old children think that the rules are set by a higher authority and cannot be changed, but the range of 10-12 years old children notice that the rules can be changed if they are compromised by individuals (Senemoğlu, 2003). In this context, considering that 3rd and 4th-grade children are in the transition period from the 6-10 age group to the 10-12 age group, 3rd-grade children are more closely attached to their responsibilities. Therefore, their level of responsibility is higher. Güdürü (2021) examined the relationship between secondary school student's level of responsibility, age, and grade level. He found that the level of responsibility of the students decreased as their grade level and age increased. Özcan examined the relationship between secondary school students' responsibility levels and grade levels. He found that the responsibility levels of the 5th and 6th-grade pupils are higher than the responsibility levels of the 7th and 8th-grade pupils. In this context, the results are similar to the results of research by Güdürü (2021) and Özcan (2021).

We analysed the relationship between the birth order of the students and their science lesson-focused responsibility level. We found that birth order did not affect the level of responsibility. We also analysed the relationship between birth order and responsibility level sub-factors. We found that there was no statistically significant difference between all sub-factors and birth order. The research results are consistent with those of Yıldırım (2016). However, Alfred Adler claimed that individuals have power struggles in their lives. This situation starts to occur in the family. Individuals strive to establish superiority among siblings and prove themselves. Therefore, Adler suggested that birth order causes differences in the personality traits of siblings (as cited in Gustafson, 2010). In the literature, first-born individuals are defined as being responsible, perfectionist, independent, ambitious, aggressive, successful, having a leadership spirit, and being fond of their mother in studies of the relationship between birth order and personality traits. Middle children are defined as being extrovert, jealous, brave, and talkative, while last-born children are defined as being extroverted, compassionate, and less responsible individuals. Only children are selfish individuals who are fond of their freedom (Gustafson, 2010; Herrera et al., 2003; Nyman, 1995; Semerci, 2017). However, since the studies are the results obtained by referring to the opinions of individuals, the family's attitude towards child-rearing, environmental conditions, and many underlying factors need to be included in the research process.

We analyzed the relationship between the number of siblings of students and their responsibility levels. We found that the number of siblings did not affect the level of responsibility. However, as the number of siblings increased, the average responsibility scores also increased. This finding can be interpreted as individuals from larger families fulfilling their own responsibilities and taking on additional responsibilities as the number of siblings increases. We analyzed the relationship between the sub-factors of science lesson-focused responsibility levels and the number of siblings. We found that there was no statistically significant difference between any of the sub-factors and the number of siblings. Aladağ (2009) concluded that there was no significant difference between responsibility levels and the number of children of the family. Also, Yıldırım (2016) concluded no significant difference between the number of siblings and the level of responsibility in research examining the relationship between personal responsibility and mental health levels in secondary school students. Similarly, Güdürü (2021) examined the responsibility levels of secondary school students and found that there was no significant difference between the number of siblings and the level of responsibility of the students. The findings of this study are consistent with the research by Aladağ (2009), Güdürü (2021), and Yıldırım (2016).

We analysed the relationship between pupils' preschool experience and their responsibility level. We found that the preschool experience did not affect the level of responsibility. After, we examined relationship between responsibility level sub-factors and the preschool experience. We found that there were no statistically significant differences between "Conscious Resource Consumption", "Safety Awareness", "Environmental Awareness" sub-factors and preschool experience. The "Health Consciousness" sub-factor showed a statistically significant difference in favour of those who had no preschool experience, contrary to expectations. Preschool experience is preparing children for primary school and significantly contributes to cognitive, affective, psycho-social, psychomotor, self-care, and language development (Bütün Ayhan & Aral 2007). In literature, it is concluded that preschool-experienced students are better level in multiple areas of development than those who have not, in the later stages of their educational lives. But there are no findings in the context of responsibility in the studies conducted (Oktay, 2007; Stipek & Byler, 2001; Yoleri & Tanış, 2014).

We analyzed the relationship between maternal education and the student's responsibility levels. First, we found that there were no statistically significant differences between the maternal educational level and the student's responsibility level. Then, we analyzed the correlation between the responsibility level sub-factors and the maternal education level. We found that there were no statistically significant differences between the maternal educational level and the responsibility level sub-factors. The research results are similar to the results of research by Yıldırım (2016) and Aladağ (2009). On the contrary, our research results are different from the results of research by Güdürü (2021). He examined the level of responsibility of secondary school 5th, 6th, 7th, and 8th-grade students whose mother was primary school graduate and whose mother was illiterate. And he found that the level of responsibility of the students whose mother is a primary school graduate is higher than that of those whose mother is illiterate.

We analyzed the relationship between the father's education and the student's responsibility levels. First, we found that there did not have statistically significant differences between the father's educational level and the student's responsibility level. Then, we analyzed the relationship between the science lesson-focused responsibility level sub-factors and the father's education level. Likewise for paternal education, we found that there did not have statistically significant differences between the father's educational level and the responsibility level sub-factors. The results are similar to the results of research by Yıldırım (2016) and Güdürü (2021). On the contrary, the results are not similar to those of studies conducted by Aladağ (2009) and Uyanık et al. (2016). These studies found that increasing the father's educational status contributes more positively to the children's responsibility levels and personality development.

We examined the relationship between the pupils' science lesson interest levels and their responsibility level. We found that as the level of interest increases, their responsibility levels increase. Then, we examined the relationship between the responsibility level sub-factors and interest level. We found that there was a statistically significant difference between all sub-factors and interest levels ("I like it," "I like it a little," and "I do not like it") in favour of those who "I like it" the lesson. Interest is an influential and significant factor in learning (Harty & Beall, 1984, p. 423). As interest increases, success increases. Therefore, learning is fast and permanent (Laçin Şimşek & Nuhoğlu, 2009). Based on research in the literature about the relationship between science education and interest/curiosity, Koran and Longino (1982) concluded that learners with high interest-curiosity have higher levels of understanding the information than those with low levels of interest. Interested pupils can keep the acquired information in memory for a long time, perform complete learning, and are more successful in lessons.

Suggestions

According to the research results, boy students' level of responsibility is lower than girl students. For this reason, teachers can assign tasks to boy students to increase their level of responsibility.

According to the results of the research, student's interest in science lessons positively affects their level of responsibility. Responsibility, interest, and motivation are essential components to o increase academic success (Brecke & Jensen, 2007; Martel et al., 1987). Therefore, the science curriculum and lesson books should be prepared based on practices that increase students' curiosity and interest.

Teachers can carry out social assistance studies in order to give students individual and social responsibility. They can increase their awareness of their socioscientific problems and encourage them to produce solutions with argumantation based activities for this problem.

Families are role models for children. For this reason, the fact that parents are responsible people is an important factor for their children to be responsible individuals. Before we started our research, we thought that as the level of family education increased, the level of responsibility of the students would increase. However, our research results surprised us. As a result of our research, we found that there was no significant difference between parental education status and student responsibility levels. We examined studies in the literature that found a significant difference between these two concepts. For this reason, future researchers can conduct studies that examine the relationship between parental education level and responsibility in detail.

In our research, we found that there was no significant difference between birth order and level of responsibility. Similarly, in many studies in the literature, no significant relationship was found between birth order and responsibility. However, many educators and parents think that birth order affects the level of responsibility. Therefore, future researchers can examine the relationship between birth order and level of responsibility in more detail by considering other variables with an ethnographic research design, which is a qualitative research design.

Preschool education is an important education period that prepares students for primary school life and provides them with various skills. Although we think that preschool experience has a significant effect on responsibility, we found that there was no significant difference between the level of responsibility and preschool education experience in our research. For this reason, future research can conduct research that will examine the relationship between these two concepts in detail.

Conflicts of Interest

There are no conflicts of interest to declare.

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Developing a Turkish adaptation of the connectedness to nature scale

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ABSTRACT
The aim of this study was to adapt the Affective, Behavioural, and Cognitive Connectedness to Nature Scale (ABC-CNS), which was developed by Cuadrado et al. (2022) and focuses on the affective, behavioural and cognitive components of the interrelationships between knowing, feeling and doing towards the natural environment, into Turkish conditions. The linguistic equivalence study of the scale was conducted by using the final Turkish form and the English forms, and was conducted using to 45 English teachers all of whom were native Turkish speakers and proficient in English.The collected data were analysed t using the hrough dependent samples *t* test, and no significant differences were found between the responses of the respondents to the Turkish and English forms (p<.01). In the next stage, for the purpose of validity and reliability, the Turkish form was administered to 300 participants aged 18 and over from different regions and various occupational groups in Turkey. Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) were conducted as part of validity and reliability studies. According to the results of the factor analysis, it was concluded that the adapted scale in Turkish is a valid scale with three dimensions, which are intrinsic to the original structure of the instrument. The internal consistency reliability of the scale was calculated through Cronbach Alpha and reached 0.90. The adapted ABC Connectedness to Nature Scale (ABC-CNS) is a valid and reliable scale that can be used to reveal the cognitive, affective and behavioural aspects of the connection between Turkish living adults and nature.

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Introduction

Although humans are inherently dependent on natural resources (Tam, 2013), the dramatic increase in urbanisation (United Nations Department of Economic and Social Affairs, 2018) has resulted in people spending less time in nature than ever before (Leung et al., 2022). The relationship between humans and nature is characterised by mutual interaction and endures throughout a lifetime (Özalemdar, 2021). The rising demands of an increasing population, driven by scientific and technological advancements, have led to excessive and unmindful exploitation of natural resources, consequently disrupting ecological balance and causing regional and global issues that affect humanity (Köğce et al., 2008). The radical changes necessary for a sustainable future, with the interrelationship between climate change, depletion of natural resources, and biodiversity loss, require humans to establish a new relationship with nature (Ives et al., 2018). Rethinking the human-nature relationship is seen as a leverage point for sustainability by many researchers (Folke et al., 2011) and is identified as a significant area of research (Fischer and Riechers, 2019). Therefore, establishing a new relationship with nature requires interventions and approaches that can bring about large-scale changes across complex systems (Richardson et al., 2020).

The conceptualization of nature among humans are influenced by their physical interactions with natural environments and by whether they reside in an urban or rural setting, which subsequently shape their understanding of nature encounters (Faruhana et al., 2022). The relationship between humans and nature, mirroring the interdisciplinary field of sustainability science, has become a shared research area for psychologists, environmental psychologists, ecologists, sociologists, educators and scientists from various fields (Tam, 2013; West et al., 2020). This is because the boundaries of the human-nature relationship are not fully defined, and therefore, a more comprehensive understanding can be achieved through an interdisciplinary approach to the issue (McMichael et al., 2003).

Literature Review

In recent years, environmental psychologists have shown interest in the concept of "Connectedness to Nature "as it defines the human-nature relationship and is believed to play an important role in mitigating the environmental crisis (Tam, 2013). Connectedness refers to the extent to which individuals include nature in their cognitive representation; connectedness to nature is a multidimensional psychological construct (Harvey et al., 2020). Connectedness to nature represents an individual's experiential sense of connection to the natural world, reflected in an affective or cognitive perspective (Mayer and Frantz, 2004), and it is also a significant predictor of environmental behaviour (Whitburn et al., 2020). Connectedness to nature is important for both the psychological well-being of individuals and the increase in pro-environmental behaviours (Richardson et al., 2020) because when individuals feel connected to nature, they recognise that harming nature ultimately harms themselves (Mayer and Frantz, 2004; Nisbet et al., 2009).

Schultz (2002) identifies three core structural components, namely connectedness, caring and commitment, to understand the human-nature relationship. Connectedness is considered cognitive, caring is affective, and commitment is behavioural. Based on this definition, human-nature connectedness appears to be a subjective construct consisting of at least three interrelated dimensions: cognitive (knowledge and beliefs about nature), affective (feelings and emotions towards nature), and behavioural (actions and experiences in nature) (Nisbet et al., 2009; Zylstra et al., 2014; Whitburn et al., 2020).

In the early 2000s, empirical research on measuring human-nature relationships and investigating factors that influence this relationship increased, leading to the development of various scales. Schultz (2002) introduced the concept of "Inclusion of nature in self"(INS), Clayton (2003) proposed "Environmental identity"(EI), Mayer and Frantz (2004) developed the "Connectedness to nature"(CTN) scale, Miller and Johnson (2008) focused on motivation for change, Davis et al. (2009) examined "Commitment to nature"(CON), Nisbet et al. (2009) explored "Nature relatedness"(NR), Perkins (2010) studied love and care for nature, Milfont and Duckitt (2010) developed the "Environmental Attitude Inventory," and Barnes et al. (2021) created the "Nature Connectedness Parental Self-Efficacy Scale," among others. Reviewing the literature, it can be observed that there are two scales have already been adapted for use in the Turkish context: the "Nature Relatedness Scale" by Çakır et al. (2015) and the "Connectedness to Nature scale "by Bektaş et al. (2017), which is an adaptation of the scale developed by Mayer and Frantz (2004). These scales are intended to measure emotional attachment and connections derived from experiences with nature. Their adaptation for the Turkish context involved not only linguistic translation but also necessary contextual modifications to ensure both cultural and contextual relevance. However, no comprehensive scale has been identified that examines the human-nature relationship in its affective, behavioural and cognitive dimensions.

To maintain a sustainable relationship with nature, it is important to ensure the well-being of the environment itself. However, environmental issues both globally and in Turkey are compromising this state of well-being. Climate change (Sıygın and Afacan, 2020; Şen, 2022), global warming (U.S. Global Change Research Program, 2023), air pollution, depletion of natural water resources (Şen, 2022; Yüzüak and Erten, 2022), water pollution (iklimin.org, 2020; Yümün et al., 2023), drought (Erdem and Bilgili, 2023), waste management issues (Kizioğlu, 2023), mass migration (Karagözoğlu, 2020), and unplanned urbanisation (Kutsal and Polatoğlu, 2023) are among the environmental problems affecting the natural environment in Turkey due to its geological location, climate characteristics, and structure, leading to a higher occurrence rate (Öztürk and Ünlü, 2022; Şen, 2022; Yüzüak and Erten, 2022). In addition, both human-induced and natural disasters such as earthquakes, landslides and forest fires also cause harm to the environment (Çelik et al., 2020).

Turkey is considered one of the countries at risk in terms of the potential impacts of global warming, as highlighted in international publications and reports (Climate Change, 2007). According to the Köppen-Geiger method widely used for climate classification worldwide, Turkey has approximately 18% of its land characterised by arid climates (Öztürk and Ünlü, 2022). As a result of a global temperature increase of 1 °C, it is anticipated that the arid zones will shift about 250 km to the north, making Turkey one of the most affected countries (Şen, 2022; UNEP, 2020). Additionally, due to increasing drought and decreasing natural water resources, it is expected that Turkey will become one of the water-stressed countries by 2050 (Turan, 2018). In terms of living dynamics, it is evident that these impacts will not be limited to the natural environment alone but will also adversely affect all areas that humans are dependent on, such as the economy, agriculture, industry, tourism, food production, livestock and social life (iklimin.org, 2020).

According to research, environmental insensitivity and lack of education are identified as the primary causes of environmental problems in Turkey (Karagözoğlu, 2020). Consequently, fostering conscious awareness and responsibility toward the environment among all members of society is imperative (Kiziroğlu, 2023). This underscores the critical need for comprehensive nature education, as emphasised by Özata-Yücel and Özkan (2014), to equip individuals with the knowledge, attitudes and awareness necessary for addressing environmental challenges and promoting sustainable interactions with nature. Positive environmental change can only be achieved when individuals modify their behaviour and adopt lifestyles that benefit nature (Sıygın and Afacan, 2020). Thus, to sustain Turkey's development without compromising its biodiversity, it is crucial to educate society and promote conservation awareness, ensuring the preservation of nature and biodiversity for future generations (Tergenbayeva et al., 2023).

As for national studies conducted in Turkey, Çakır et al. (2015) measured individuals' attachment to nature by associating it with individuals' well-being in the "Relationship with Nature" scale adapted for use in Turkey by Çakır et al. (2015), while Bektaş et al. (2016) adapted the scale of attachment to nature and addressed attachment to nature in the dimension of emotional experience. In this context, there is no study that has adapted or developed the commitment to nature with affective, behavioural and cognitive dimensions into Turkish as a unity yet.

The studies conducted internationally to develop scales aiming to describe the human connection to nature examined individuals' attachment to nature; Mayer and Frantz (2004)'s Connectedness to Nature Scale (CTS), Dunlap et al. (2000)'s The new environmental paradigm (NEP) scale, Nisbet and Zelenski (2009)'s connectedness to nature scale, the self-concept and the individual's relationship with the environment, and Navarro et al. (2017)'s connectedness to nature as a sense of belonging to the natural world. When the scales in the literature are examined, it is seen that the dimensions of each of them take into account cognitive and affective characteristics in different ways. However, there is a need to develop a more holistic scale that includes affective, behavioural and cognitive dimensions (Sevillano, et al. 2017). The A(affective)-B(behavioural)-C(cognitive) Connectedness to Nature Scale (ABC-CNS), which was developed by focusing on this need and focuses on 3 dimensions: affective, behavioural and cognitive, considering the balance of the relationship between knowing, feeling and doing, is suitable for cognitive, affective and behavioural assessments of individuals' attachment to nature (Cuadrado et al., 2022).

Given Turkey's status in the current "global alarm"situation, the adaptation of the holistic scale developed by Cuadrado et al., 2022 for Turkish use is considered an urgent need to reveal the connection between Turkish individuals and nature and plan individual and social change steps accordingly. This is because strengthening the human-nature connection requires first understanding how individuals feel in nature and defining their relationship with nature (Ives et al., 2018).

Aim and Objectives of the Study

The primary aim of this study is to adapt the ABC (Affective-Behavioural-Cognitive) Connectedness to Nature Scale (ABC-CNS), developed by Cuadrado et al. (2022), for use in the Turkish context. Specifically, the study seeks to evaluate the linguistic equivalence of the ABC-CNS in Turkish, ensuring that the scale retains its conceptual integrity after translation and adaptation. Additionally, the study aims to assess the psychometric validity of the adapted ABC-CNS among Turkish-speaking individuals, examining its reliability and consistency across the affective, behavioural, and cognitive dimensions of nature connectedness.

Methods

This section provides information about the research sample, the process of obtaining permission and translation, the data collection instruments utilised, the implementation process, and the statistical analyses performed on the collected data.

Research Model

The objective of this research was to perform a comprehensive examination of the validity and reliability of the adapted Turkish version of the ABC Connectedness to Nature Scale (ABC-CNS). To this end, a research design utilising a descriptive survey approach was employed. Descriptive survey research aims to provide a comprehensive understanding of a specific group's characteristics through the implementation of various data collection instruments, including interviews, questionnaires, and tests (Fraenkel and Wallen, 2009).

Study Group

This research consisted of two distinct study groups. The first study group used during the linguistic equivalence phase and consisted of a total of 45 individuals, including 32 females and 13 males, within the age range of 25 to 56. The second study group, utilized for the analysis of validity and reliability, comprised a total of 300 participants, with 206 females and 94 males, ranging in age from 18 to 56. The study sample was constructed using a convenience sampling method, as described by Fraenkel and Wallen (2009), where participants were selected based on their accessibility and willingness to participate in the study.

The demographic characteristics of the participants involved in the linguistic equivalence study are detailed in Table 1, while Table 2 provides the demographic details of the participants involved in the validity and reliability studies.

Table 1

Demographic information of participants involved in the linguistic equivalence study

		n	%
Gender	Female	32	71%
	Male	13	29%
Age	18-24	1	2%
	25-34	22	49%
	35-45	18	40%
	46-55	3	7%
	56 and above	1	2%
Fields of Study	English Language Teaching	41	91%
	Translation and Interpreting	4	9%
Educational Level	Bachelor's degree	24	53 %
	Master's degree	17	38%
	Doctorate degree	4	9%
Total		45	100,00%

Table 2

Demographic information of participants included in the validity and reliability study

		n	%
Gender	Female	206	68.67%
	Male	94	31.33%
Age	18-24	16	5.33%
	25-34	126	42.00%
	35-45	100	33.33%
	46-55	38	12.67%
	56 and above	20	6.67%
Occupation	Lawyer	3	1.00%
	Banker & Financial Specialist	4	1.33%
	Information Technology& IT Specialist	5	1.67%
	Civil Servant	1	0.33%
	Dentist	1	0.33%
	Doctor	26	8.67%
	Engineer	20	6.67%
	Academician & Instructor	16	5.33%
	Teacher	122	40.67%
	Marketing& Communication Specialist	11	3.67%
	Police	1	0.33%
	Other	90	30.00%
Educational Level	High School	30	10.00%
	Associate's degree	16	5.33%
	Bachelor's degree	130	43.33%
	Master's degree	97	32.33%
	Doctorate	27	9.00%
Total		300	100.00%

Data Collection Instruments

In this study, a 5-point Likert-type scale was used to collect data. The instrument consisted of three sections: an informed consent form, a demographic information form, and the ABC Connectedness to Nature Scale.

Demographic Information Form

This form, prepared by the researcher, included four questions addressing participants' gender, age, highest level of education completed, and occupation. Measurement Instrument: Characteristics of the Original Affective-Behavioural-Cognitive (ABC) Connectedness to Nature Scale (ABC-CNS).

The original version of the ABC (Affective-Behavioural-Cognitive)- CNS (Connectedness to Nature Scale) consists of a total of 15 items. Based on a three-dimensional framework rooted in the concept of attitudes, the ABC-CNS was developed to analyse individuals' level of affective, behavioural, and cognitive connectedness to nature. These dimensions include;

A: Affective- how individuals affectively perceive themselves in relation to nature,

B: Behavioural-their inclination to behave as a part of the natural world,

C: Cognitive- how they perceive themselves in terms of nature.

Correspondingly, the scale is divided into three factors or dimensions (affective, behavioural and cognitive) that form different aspects of an individual's relationship with the natural environment. Each of these factors consists of five items, evaluated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Regarding the item structure of the scale, three items were directly translated from other scales, six were adapted from previous scales, and the remaining six were newly created based on the intended purpose.

The study sample consisted of 1375 students, of whom 878 (63.9%) were Ecuadorian (age range = 18-45) and 497 (36.1%) were Spanish (age range = 18-49). Exploratory and confirmatory factor analyses were conducted to ensure the validity of the scale. Prior to conducting the exploratory factor analysis, the researchers assessed the suitability of the correlations for factor analysis using the Kaiser-Meyer-Olkin index (0.943) and Bartlett's test of sphericity ($\chi 2 = 8931.093$; df = 105; $p < .001$). The results indicated that the correlations were suitable for exploratory factor analysis. As a result, three factors were identified, explaining 69.75% of the variance, and all items loaded appropriately onto their proposed dimensions. The cross-cultural invariance of the three-dimensional structure found in the exploratory factor analysis was tested using multi-group confirmatory factor analysis. The results were within statistically acceptable limits.

The factor loadings of the items in the scale ranged from 0.62 to 0.90. The reliability of the scale was assessed using Cronbach's alpha coefficients, ranging from .73 to .96, and H coefficients, ranging from .80 to .98, as recommended. These coefficients demonstrated acceptable levels of reliability for each of the three factors across all samples examined.

Implementation Process

To adapt the ABC Connectedness to Nature Scale (ABC-CNS) for Turkish conditions, an email was sent to Esther Cuadrado, the original scale developer and responsible author, to obtain permission for the adaptation.

The translation-back translation method was employed to translate the scale into Turkish. In the first stage, three experts proficient in the English language translated the scale into Turkish. One of the translators was an academic teaching English Translation at the university, while the other two had undergraduate degrees in English Language Teaching. In the second stage, the different translations were compared, and areas of discrepancy were identified. The translators were brought together to reach a consensus on the items with discrepancies. In the third stage, the final version of the translated form was presented to a Turkish language expert proficient in both English and Turkish for evaluation. The final Turkish version of the form was sent to three different experts, specialising in

English Language and Literature and Translation and Interpretation, to re-translate the form into English. The re-translated English form was then sent to an expert proficient in English and knowledgeable in Turkish for review, with minor adjustments made to 1-2 words. Thus, both forward and backward translation methods, which are necessary to ensure language validity in scale adaptation studies (Boztunç Öztürk, et al., 2015), were completed separately in this study.

The English and Turkish versions of the scale were administered to a group of English teachers using Google Forms, with a one-week interval between administrations. The correlation analysis conducted on the data obtained from the administration revealed a statistically significant relationship, indicating that the responses given to the Turkish and English forms were associated. In this context, the final version of the Turkish form was prepared to be administered digitally on Google Forms. The form was administered to 300 participants aged 18 and above, representing a diverse range of professional and academic backgrounds from various cities across Turkey, over a 15-day period in April 2023. After the completion of the administration, the collected data were subjected to data analysis.

Data Analysis

Before conducting the validity and reliability analyses of the scale, data accuracy, minimum-maximum values, and missing data analysis were performed. Based on these analyses, no missing data was found, and the validity and reliability analyses were conducted using the responses of the 300 participants.

In adaptation studies, although exploratory factor analysis (EFA) is generally used for scale development studies, it can also be used to test whether the original item interpretations do not alter in the process of translation into a new language (Seçer, 2015). EFA and CFA can be used together in scale adaptation studies, the purpose of which is to confirm the latent construct identified by EFA (Osborne & Fitzpatrick, 2012). In scale adaptation studies, CFA also checks the model fit between the factor structures of the original version and the translated version (Seçer, 2015). Sousa and Rojjanasrirat (2011) listed verifying the factor structure as the sixth step in scale adaptation studies and determining the model fit as the seventh step. Therefore in this study Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) were conducted to determine the construct validity by analyzing the collected data. The SPSS and AMOS software packages were used for data analysis. For the reliability analysis, the Cronbach's alpha reliability coefficients of the sub-dimensions of the model obtained from the EFA and CFA results were examined.

Ethical Considerations

In accordance with research and publication ethics principles, all participants in the study were provided with necessary information regarding the purpose of the research, and voluntary participation was ensured. Personal information that could reveal the identities of the participants was not requested. The analysis, interpretation, and reporting of these data were conducted in accordance with ethical principles. The entire process was completed within the framework of the document numbered 20230402014, dated 05.04.2023, obtained from the Yildiz Technical University Ethics Committee to facilitate the execution of the research.

Findings

Linguistic Equivalence Findings

To test the linguistic equivalence of the scale, the English version of the scale was administered first, followed by the Turkish version. The results of the correlation analysis for the total scores obtained from the scales indicate a near-perfect positive correlation between the English and

Turkish forms of the scale ($r = .95$, $p < .01$). The results of the correlation analysis are presented in Table 3.

Table 3

Item total correlation analysis between the English and Turkish versions of the scale

	N	*p*	*r*
Turkish Version English Version	45	0.00*	.95

Note. p <.01

To determine whether there was a statistically significant difference between the Turkish and English items of the scale, a paired samples t-test was conducted. The results showed that there was no statistically significant difference between the mean scores of the original English items and the Turkish items [$t(45) = 2.103$, $p < 0.01$]. This indicates that the ABC Connectedness to Nature Scale (ABC-CNS) meets the condition of linguistic equivalence. The results of the paired samples t-test analysis are illustrated in Table 4.

Table 4

Results of the Dependent Samples t-Test Analysis Examining the Relationship between Turkish and English Scale Items

	N	*X̄*	*Ss*	*Sd*	*t*	*p*
Turkish Version	45	59.89	10.63	44	2.10	0.41
English Version	45	58.73	11.57			

Note. p<.01

Findings Regarding Validity

To test the construct validity of the ABC Connectedness to Nature Scale (ABC-CNS) and confirm the structure of the original scale, exploratory and confirmatory factor analyses were conducted.

Exploratory Factor Analysis

Exploratory factor analysis is an analysis that uses the relationships between items in the measurement tool to identify appropriate factors (Osborne and Fitzpatrick, 2012). The Kaiser-Meyer-Olkin (KMO) coefficient was calculated and the Bartlett's test of sphericity was performed to assess the suitability of the data for factor analysis. The results are provided in Table 5.

Table 5

Results of KMO coefficient and Bartlett's test

KMO Coefficient		.87
Bartlett Test		
	Approx. Chi-Square ($\chi 2$)	2181,266
	df	105
	Sig.	.000*

Note. p<0.001

When examining the values in the table, it can be seen that the KMO coefficient is within acceptable limits (1.00 ≥ KMO ≥ 0.70) and the Bartlett's test of sphericity is statistically significant at p = .00 (p < .05) level. These results indicate that the data is assumed to come from multivariate normal distribution and is suitable for factor analysis (Field, 2009).

During the exploratory factor analysis, a minimum item loading value of .30 was considered to identify the items that should not be included in the adapted scale but were present in the original scale (Pallant, 2005). Additionally, a minimum difference of .10 between factors was considered to avoid overlapping items in the scale (Büyüköztürk, 2015). Eigenvalues and percentage of variance were utilized to determine the number of factors that could reveal the relationship between the items in the construct validity, and a direct oblimin rotation method was used for factor rotation. In the oblique rotation method, which is used when factors are correlated (Büyüköztürk, 2015), the pattern matrix represents the relationship between the observed variables and the factors (Tabachnick and Fidell, 2012). In this sense, the pattern matrix table was examined to identify the items within the factors. Furthermore, the eigenvalues table was checked for total scores with eigenvalues of 1.0 and above. As a result of the analysis, three factors were obtained. It was found that, similar to the original version, the Turkish form of the scale also comprises three factors. These factors were labelled as Cognitive, Affective, and Behavioural to align with the corresponding dimensions of the adapted scale.

Table 6

Eigenvalues and explained variance ratios of the emerged factors

Factor (F)	Eigenvalue	Explained Variance %	Cumulative %
Cognitive (F1)	6,14	40,93	40,93
Affective (F2)	1,67	11,11	52,04
Behavioural (F3)	1,26	8,42	60,46

The scale with three factors explains a variance ratio of 60.46%. The factor loadings of the obtained factors are summarized in Table 7.

Table 7

EFA results of ABC Connectedness to Nature Scale

Items	Factor Communalities	Factor 1 (Cognitive)	Factor 2 (Affective)	Factor 3 (Behavioural)
M1	0,670	0,839		
M2	0,674	0,878		
M3	0,681	0,778		
M4	0,649	0,716		
M5	0,578	0,717		
M6	0,576		0,637	
M7	0,606		0,771	
M8	0,618		0,542	
M9	0,625		0,660	
M10	0,395		0,668	
M11	0,392			0,486
M12	0,887			0,967
M13	0,369			0,503
M14	0,872			0,968
M15	0,476			0,558

As depicted in Table 7, when examining the factor loadings, it can be observed that the lowest factor loading is .48 and the highest loading is .96, indicating that all items load onto the three factors. Factor loadings between 0.30 and 0.59 indicate a moderate level of relationship, while loadings of 0.60 and above indicate a high level of relationship (Büyüköztürk, 2015).

Confirmatory Factor Analysis

To determine whether the three-factor structure obtained from exploratory factor analysis is confirmed, confirmatory factor analysis (CFA) was conducted using AMOS 23 software. For this analysis, the chi-square goodness-of-fit test, goodness-of-fit index (GFI), adjusted goodness-of-fit index (AGFI), comparative fit index (CFI), non-normed fit index (NNFI), root mean square residual (SRMR), and root mean square error of approximation (RMSEA) were examined. The values obtained were $\chi2$ /df = 2.40, CFI = .95, NNFI = .94, RMSEA = .068, and SRMR = 0.54. These values indicate that the three-factor structure of the scale is acceptable and provides valid results (Browne and Cudeck, 1993; Byrne, 2011; Kline, 2011). The significant values and levels of fit indices are listed in Table 8.

Table 8

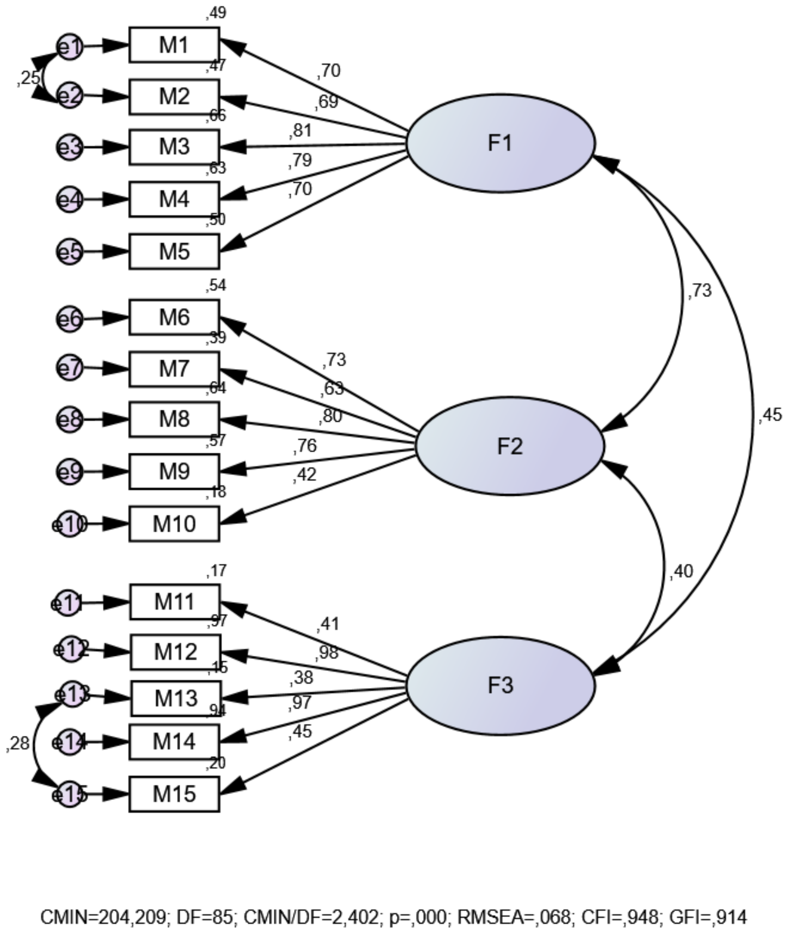
Indices of fit related to CFA

Analysed Fit Indices	Perfect Fit Criteria	Acceptable Fit Criteria	Obtained Fit Indices	Result
χ^2/sd	$0 \leq \chi^2/sd \leq 2$	$2 \leq \chi^2/sd \leq 3$	2,40	Perfect Fit
GFI	.95 ≤ GFI ≤ 1.00	.90 ≤ GFI ≤ 95	.91	Acceptable Fit
AGFI	.90 ≤ AGFI ≤ 1.00	.85 ≤ AGFI ≤ .90	.88	Acceptable Fit
CFI	.95 ≤ CFI ≤ 1.00	.90 ≤ CFI ≤ .95	.95	Perfect Fit
NFI	.95 ≤ NFI ≤ 1.00	.90 ≤ NFI ≤ .95	.90	Acceptable Fit
NNFI	.95 ≤ NNFI ≤ 1.00	.90 ≤ NNFI ≤ .95	.94	Perfect Fit
RMSEA	.00 ≤ RMSEA ≤ .05	.05 ≤ RMSEA ≤ .08	.068	Acceptable Fit
SRMR	.00 ≤ SRMR ≤ .05	.05 ≤ SRMR ≤ .10	.054	Acceptable Fit
PGFI	.95 ≤ PGFI ≤ 1.00	.50 ≤ PGFI ≤ .95	.65	Acceptable Fit

Based on the conducted confirmatory factor analysis in light of these data, it has been determined that all items in the factors are significant for their respective factors. The path diagram depicting the factor structure of the items can be seen in Figure 1.

Figure 1

Confirmatory factor analysis model for ABC Connectedness to Nature Scale (ABC-CNS)



Reliability Findings

Internal Consistency (Cronbach's Alpha) Coefficients

In order to determine the internal consistency reliability of the scale, Cronbach's Alpha coefficients were examined for the overall scale and its sub-dimensions. The Cronbach's Alpha coefficient was found to be .87 for the Cognitive (F1) sub-dimension, .81 for the Affective (F2) sub-dimension, and .80 for the Behavioural (F3) sub-dimension. Additionally, the internal consistency coefficient for the entire scale was calculated as .90. The reliability calculations for the 15-item scale are displayed in Table 9.

Table 9

Reliability coefficients of ABC Connectedness to Nature Scale (ABC-CNS)

Cronbach's Alpha Coefficient		.90
Inter-Form Correlation		.84
Spearman-Brown Coefficient	Equal Length	.91
	Unequal Length	.91
Guttman Split-Half Coefficient		.91

Based on the Cronbach's Alpha coefficient value above .80, it can be concluded that the scale is highly reliable (Field, 2009).

Conclusion and Recommendation

In this study, the adaptation, validity, and reliability of the ABC Connectedness to Nature Scale (ABC-CNS), developed by Cuadrado et al. (2022), which examines the relationship between feeling, doing and knowing in nature through the three dimensions of affective, behavioural and cognitive aspects, were conducted in Turkish. After the translation of the scale into Turkish was completed, data obtained from the applications conducted with a group of 45 participants at two-week intervals revealed no statistically significant difference between the English and Turkish versions of the scale.

The validity and reliability studies of the research were carried out with a sample of 300 adults aged 18 and over from different cities and occupational groups in Turkey. Exploratory and confirmatory factor analyses were performed using the data obtained from this group. According to the results of the exploratory factor analysis, a three-factor structure consistent with the original scale was identified. The factor loadings of the items ranged from .48 to .96, and the items in the scale accounted for 60.46% of the variance. In the original scale, these three factors account for 69.75% of the variance, and the factor loadings range from .62 to .90 (Cuadrado et al., 2022). The three-factor structure of the scale was confirmed by the results of the confirmatory factor analysis. There were no reverse-scored items in the scale.

The internal consistency reliability studies conducted to determine the reliability coefficient of the ABC-CNS (ABC Nature Connectedness Scale) have shown that the Cronbach's Alpha coefficient is .90. In tests applied in social sciences, a reliability value of .70 and above is considered sufficient for the reliability of the scale (Büyüköztürk, 2015). Therefore, the Cronbach's Alpha reliability coefficient of the scale has been measured at an appropriate level.

Following the conducted analyses, it has been ascertained that the Turkish version of the ABC Connectedness to Nature Scale (ABC-CNS) is a valid and reliable instrument for measuring nature connectedness. The scale has demonstrated its utility as a tool suitable for use among Turkish adults aged 18 and above.

The global environmental challenges facing Turkey, including climate change, biodiversity loss, and environmental pollution, highlight the critical importance of fostering a stronger connectedness to nature (Şen, 2022). The ABC Connectedness to Nature Scale (ABC-CNS), adapted for the Turkish context, has proven to be a valuable instrument for assessing individuals' environmental awareness and their connection to nature (Perkins, 2010; Richardson et al., 2020). This scale plays a pivotal role in enhancing societal awareness of pressing environmental issues such as waste management and water scarcity. Moreover, it can be effectively utilized to inform the development of environmental policies and the implementation of localized solutions to ecological challenges (Kiziroğlu, 2023).

Additionally, the validity and reliability studies of the research were conducted on a sample of individuals from different cities and occupational groups in Turkey. This not only demonstrates the general applicability of the scale in Turkish culture but also shows that it yields reliable results among participants with different demographic characteristics.

Research indicates that the cultural context shapes individuals' environmental behaviors, emphasizing the importance of cultural appropriateness in the connectedness to nature scale (Schutz, 2002). The adaptation of the scale to Turkish culture not only helps understand connectedness to nature in Turkey but also provides a model for how similar adaptations can be made in different cultures. This can be a valuable resource for researchers working in cross-cultural environmental psychology and related fields.

For future studies, detailed methodological research on how the ABC Connectedness to Nature Scale can be adapted to different cultures and geographies can be encouraged. The Turkish adaptation of the scale has not only considered linguistic changes but also cultural and social differences, making the measurement universally relevant. This can guide international researchers who want to understand connectedness to nature in various geographical locations and perform similar adaptations. Furthermore, it opens the door to in-depth analyses on how the scale's societal change impacts and can enhance environmental awareness.

In conclusion, the adaptation of the connectedness to nature scale into Turkish is not only crucial for measuring individuals' levels of connectedness to nature but also serves as a key tool in informing and shaping environmental sustainability strategies. The scale provides a comprehensive framework for understanding how individuals relate to the natural environment, directly supporting Turkey's efforts to address pressing environmental challenges such as climate change, biodiversity loss, and resource depletion. This adaptation contributes to both the development of current environmental policies and the long-term sustainability needed to protect the natural environment for future generations.

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Appendix

Turkish Version of the ABC Connectedness to Nature Scale (ABC-CNS)

Boyutlar	Soru No	Sorular	Hiç Katılmıyorum	Katılmıyorum	Kararsızım	Katılıyorum	Tamamen Katılıyorum
Bilişsel Boyut	1	Doğanın ayrılmaz bir parçasıyım.					
	2	Doğayla olan ilişkim kim olduğumun önemli bir parçasıdır.					
	3	Çevremdeki doğal dünya (insan eli değmemiş doğal güzellikler) ile bir bütünlük hissediyorum.					
	4	Kendimi doğaya ruhsal olarak bağlı hissediyorum.					
	5	Doğal dünyayı ait olduğum bir topluluk olarak görüyorum.					
Duyuşsal Boyut	6	Sadece doğada olarak bile mutlu hissediyorum.					
	7	Doğaya karşı derin bir sevgi hissediyorum.					
	8	Doğayla duygusal bir bağım vardır.					
	9	Doğada olduğumda mutlu ve evimde hissederim.					
	10	Doğa ile iç içe olmak bana huzur ve dinginlik verir.					
Davranışsal Boyut	11	Sık sık kırsal alanlara ya da doğaya çıkarım.					
	12	Doğada olduğum zaman onunla bütünleşirim.					
	13	Doğayı kendi parçammış gibi korurum.					
	14	Doğayı sık sık dinler ve izlerim.					
	15	Hayvanlara insanmış gibi davranırım.					