

Research Article

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Optimizing Science Concept Learning: The Challenge of Computational Thinking Skills Integration

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Abstract

Background/purpose. 21st-century skills are essential across all aspects of life in the modern era. Pre-service elementary school teachers must also develop computational thinking skills as part of the problem-solving process—one of the most critical 21st-century competencies. These skills are critical in science learning and serve as fundamental expertise for future elementary school teachers in their profession. This study aims to analyze the learning of science concepts in the Natural Resources and Energy course and to describe the implementation of computational thinking skills integration into the learning of science concepts in the same course.

Materials/methods. This research employs a survey method, utilizing observation sheets and questionnaires as instruments. The study involved 198 students from the Elementary School Teacher Education program at the Faculty of Teacher Training and Education, Universitas Sebelas Maret.

Results. Findings indicate that science concept learning in the Elementary School Teacher Education program has not yet effectively facilitated computational thinking skills. Observation data reveal that the current learning implementation provides insufficient stimulation for computational thinking skills, with an average rate below 50%, except for learning objectives exceeding 50%. Moreover, real-world case presentations are only incorporated at a rate of 35%. The integration of computational thinking skills in science concept learning remains significantly low. All key aspects of computational thinking—decomposition, pattern recognition, abstraction, and algorithm—score below 50%.

Conclusion. Current science concept learning practices in the Elementary School Teacher Education program need to be restructured to optimize the development of computational thinking skills among pre-service elementary school teachers.

1. Introduction

21st-century learning is a fundamental necessity in today's education system. The life skills required for the future must be nurtured throughout a person's education, from elementary school to higher education. These life skills are based on the 21st-century skills framework, known as the 7Cs: Critical Thinking, Creativity, Communication, Collaboration, Career & Learning Self-Reliance, Cross-Cultural Understanding, and Computing/ICT Literacy (Jauhariyah et al., 2021, p. 560). More specifically, developing skills that stimulate other competencies is essential, ensuring a more significant impact on mastering 21st-century life skills. One approach that supports the development of critical thinking and problem-solving abilities is computational thinking (Kong & Abelson, 2019). Similarly, computational thinking trains individuals to think critically while encouraging them to develop and apply strategies for analyzing and solving problems using technology-based methods (Hunsaker, 2020, p. 92). Denning & Tedre (2019, p. 13) describe computational thinking as a universal approach to problem-solving, indicating that it can effectively address various challenges.

Computational thinking involves logical reasoning processes in problem-solving, developing procedures and systems to understand issues, and comprehending human behavior based on fundamental computer science concepts. The concept of computational thinking was first introduced by Seymour Papert in 1980 through his book *Mindstorms: Children, Computers, and Powerful Ideas* (as cited in Lodi & Martini, 2021, p. 890). Papert explained that computational thinking could illustrate how computers enhance children's cognitive abilities by encouraging them to create meaningful products (as cited in Xu et al., 2022, p. 2). Wing (2006, p. 33) defines computational thinking as a thought process that involves problem-solving, system design, and understanding human behaviour, drawing on core concepts from computer science. Some scholars also define computational thinking skills as a conceptual foundation for solving problems efficiently through algorithmic approaches, with or without computer assistance. This approach generates solutions that can be applied across various contexts (Shute et al., 2017, p. 142).

Computational thinking skills are essential for everyday life. They are considered one of the core elements of 21st-century skills, playing a critical role in general problem-solving. These skills complement other fundamental competencies such as communication, digital literacy, critical thinking, and creativity (Tsarava et al., 2022). They are crucial for fostering systematic and logical thinking in addressing real-life challenges. This aligns with Peel et al. (2021, p. 112), who argue that computational thinking skills help individuals navigate daily challenges and better understand the world. These skills enable individuals to formulate problems and find solutions (Yuntawati et al., 2021, p. 34) and are considered an effective approach to problem-solving (Hunsaker, 2020, p. 95).

Data indicate that problem-solving and cognitive skills among students in Indonesia remain relatively low. According to the Programme for International Student Assessment (PISA), an international assessment measuring critical thinking in problem-solving, Indonesia ranked 63rd out of 73 countries in 2022. Indonesia's scores were below the OECD average, with 366 in mathematics (compared to the OECD average of 472), 359 in reading (compared to 476), and 383 in science (compared to 485) (OECD, 2023). Additionally, studies in Indonesia reveal that students' computational thinking skills are still at a low level (Jamalludin et al., 2022; Kamil et al., 2021; Lestari & Roesdiana, 2023; Sinaga, 2022). Therefore, mastering computational thinking is crucial for all individuals to enhance their critical thinking and problem-solving abilities, including university students.

Higher education institutions implement an andragogical approach to learning. Andragogy refers to education designed for adults, emphasizing independent learning. In this context, university students are expected to take responsibility for their learning. Higher education should not only focus on cognitive knowledge but also equip students with life skills relevant to the demands of the 21st

century. Preparing a workforce proficient in 21st-century skills can be achieved effectively through education, starting from elementary school to higher education (Mestry, 2017; Lase, 2019). According to Arnyana (2019), universities in Indonesia have adapted educational methods to ensure students acquire both technical skills relevant to their courses and the 4Cs (Critical Thinking, Communication, Collaboration, and Creativity) as part of their soft skills development. Ideally, 21st-century skills—including computational thinking—should be facilitated in higher education to provide students with practical competencies that benefit their future careers.

An elementary school teacher is one profession that plays a crucial role in human development in Indonesia. Elementary school is a critical period for students to develop foundational skills such as thinking, literacy, problem-solving, and other essential life skills. One of the key competencies that should be fostered at this stage is computational thinking. Integrating computational thinking into elementary school learning is essential in helping students develop computational skills that will benefit them in the future (Noh & Lee, 2020). Computational thinking is critical in education because it involves systematic and logical thinking processes, guiding students to break down complex problems into manageable components (Ardiansyah, Atmojo, & Widiyanto, 2024). To ensure that elementary school students receive learning experiences that nurture essential life skills, teachers play a crucial role. Therefore, preparing high-quality teachers requires that pre-service teachers acquire the necessary life skills during their university education. This aligns with the educational philosophy of Ki Hajar Dewantara, particularly his Trilogy of Leadership, which includes the principle of *Ing ngarsa sung tuladha*—meaning that leaders (or teachers) should lead by example.

Teachers must plan effective lessons and serve as role models for their students. This view is supported by Pantić & Wubbels (2012), who state that pedagogically competent teachers can select the most effective teaching methods and strategies while making learning meaningful for students. The intended meaning is to provide learning that can stimulate students to train all the basic life competencies. Teachers' pedagogical competence and professionalism in teaching are key factors in improving the quality of education (Sulastri et al., 2020). Therefore, a competent pre-service elementary school teacher must possess computational thinking skills. Zafrullah et al. (2024) state that computational thinking skills enable teachers to design learning activities that involve logic, systematic thinking, and data analysis, which can be applied across various subjects at the elementary school level. Moreover, these computational thinking skills help teachers design innovative learning approaches that not only make it easier for students to understand the material but also hone critical thinking, problem-solving, and creativity skills (Septikasari & Frasandy, 2018). Thus, stimulating computational thinking skills for pre-service elementary school teachers should be integrated into all subjects, including those that use a science concepts approach.

The science concepts courses in the elementary school teacher education program include human and the environment, natural resources and energy, and applied science. Science concepts are fundamental knowledge that students must master and this knowledge can stimulate computational thinking skills among pre-service elementary school teachers. Nugraha (2022) explains that the essence of meaningful science concepts lies in the combination of theoretical reasoning and real scientific phenomena. Additionally, within the activities of studying science concepts, there are essential science process skills that are crucial for students' learning development, especially in gaining meaningful learning experiences and supporting the stimulation of computational thinking skills. This is because science process skills refer to the ability to process information acquired during learning, enabling students to observe, classify, interpret, predict, apply, plan, and evaluate experimental results (Putri, Astalini, & Darmaji, 2022). Given that higher education learning approaches emphasize andragogy, the science concepts course will effectively stimulate students' computational thinking skills. This aligns with Ramlawati et al. (2019), who argue that the science

process skills approach can be defined as mastering or developing intellectual, social, and physical abilities rooted in skills fundamentally dependent on students.

The specific issue addressed in this research is the lack of stimulation of computational thinking skills in science concept-based learning in the elementary school teacher education program. Preliminary observations of science education in the elementary school teacher education program show that key aspects such as planning, implementation, student engagement, the use of real-world cases, and other factors that could stimulate computational thinking skills are not yet visibly present in learning activities. Learning that does not stimulate computational thinking skills will impact students' overall abilities because computational thinking influences other skills, such as critical thinking and problem-solving. The more distant impact is seen in students' ability to produce and understand concepts. The pretest results in the human and the environment course reveal that many students experience misconceptions about quantities in problems, formulate solutions that do not align with the problems, write processes that do not correspond to formulas, and draw incorrect conclusions from problems.

These facts indicate the need for an appropriate teaching strategy to stimulate computational thinking skills in pre-service elementary school teachers. The urgency of mastering computational thinking skills drives the need for learning that equips pre-service teachers with these skills. This is because computational thinking allows future teachers to guide their students in analyzing and solving problems with a logical and structured approach (Juldial & Haryadi, 2024). It is hoped that enhancing pre-service teachers' computational thinking skills will improve the quality of education, particularly in primary education.

One of the main challenges in integrating computational thinking (CT) into learning science concepts is educators' low level of readiness and understanding regarding this approach. This is supported by Angeli and Giannakos (2020), who argue that the challenges in CT integration include teachers' limited understanding of CT, inadequate professional training, and a lack of resources to support the implementation of CT in science education contexts. Many educators still perceive CT as a skill relevant only to programming or information technology, and are therefore reluctant to associate it with basic science content. Liu (2023) also highlights that many current CT initiatives remain focused on using computational tools without deeply integrating CT into interdisciplinary learning models, thereby creating a gap between theory and practice in education.

This study makes a significant contribution to the field of science education by providing insights into the implementation of computational thinking (CT) in science classrooms. Through an analysis of actual field conditions, this research not only identifies the extent to which CT elements have been integrated into science learning but also highlights the challenges and potentials that educators can optimize. The findings of this study contribute to further research opportunities aimed at developing more effective learning models to foster computational thinking skills. Given the limitations of current learning models in facilitating problem-solving, reflective thinking, and other scientific skills, future studies may focus on designing and testing innovative instructional models that explicitly integrate the principles of computational thinking.

Computational thinking has been identified as a fundamental component in preparing individuals for the workforce (Kite et al., 2021). However, the CT community lacks a shared conceptualization of computational thinking to support its integration, critical research on CT integration is limited, and there is no consensus regarding core CT practices—these remain significant issues (Kite et al., 2021). Research on the integration of computational thinking is still sparse and at a critical stage. Since CT practices are essential for preparing individuals for the demands of the workplace, it is necessary to investigate the challenges of CT integration in order to identify solutions for future improvement.

2. Literature Review

Computational thinking (CT) has been widely recognized as a crucial skill in 21st-century education. Wing (2006) defines computational thinking as a problem-solving approach that involves designing systems and understanding human behavior using fundamental concepts from computer science. Initially introduced by Seymour Papert in the 1980s and 1996 (Malik, Prabawa, & Rusnayati, 2019), computational thinking has evolved into a cognitive process that can be applied across disciplines. Cansu & Cansu (2019) further elaborate that computational thinking enables individuals to solve problems, design systems, and understand patterns by leveraging computer science concepts.

Computational thinking is not limited to programming but extends to problem formulation and solution development, making it a valuable cognitive skill (Wing, 2011). Cahdriyana & Richardo (2020) emphasize that CT originates from computer science but can be effectively applied across different domains through structured problem-solving processes. According to Zen, Fitriana, & Gustalika (2021), computational thinking represents a problem-solving framework that facilitates efficient and logical information processing. Additionally, Mania (2021) highlights that CT fosters innovative thinking in identifying phenomena and generating practical solutions.

In the context of education, Yulianto, Azhari, & Rahani (2021) describe computational thinking as a structured method for problem-solving similar to how computer scientists approach complex challenges. Fitriani, Suwarjo, & Wangid (2021) argue that CT involves logical reasoning to create structured procedures or systems that simplify problem resolution. The ultimate goal of computational thinking, as described by Fauji, Sampoerna, & Hakim (2022), is to equip learners with the ability to apply problem-solving strategies across multiple disciplines. By stimulating computational thinking, students become better at addressing problems efficiently and systematically (Jamna, Hamid, & Bakar, 2022).

Computational thinking consists of five key cognitive processes that enable efficient and creative problem-solving: problem reformulation, recursion, decomposition, abstraction, and systematic testing (Anistyasari, Ekohariadi, & Hidayati, 2022). These processes help students break down problems, recognize patterns, and develop systematic solutions. As Rosadi et al. (2020) note, incorporating CT into education enhances students' confidence in solving problems, while Lestari & Annizar (2020) highlight its role in fostering critical thinking and efficiency.

A crucial factor in developing computational thinking skills is student engagement and enjoyment in learning. Research indicates that one of the most effective ways to enhance CT skills is through programming education (Malik et al., 2019). However, Supiarmo et al. (2021) suggest that teaching methods should be flexible and not restrict computational capabilities. Lestari & Roesdiana (2023) emphasize that integrating cognitive aspects into learning can strengthen students' high-order thinking skills, ultimately improving their computational thinking abilities.

Several key indicators define computational thinking. Wing (2006) identifies abstraction, algorithm design, decomposition, pattern recognition, and data representation as core components of CT. Ioannidou et al. (2011) further expand on these indicators, including generalization as an essential skill. Grover & Pea (2013) propose four primary computational thinking indicators: (1) Decomposition, which involves breaking down complex problems into smaller, manageable parts (Csizmadia et al., 2015); (2) Algorithmic Thinking, which refers to developing step-by-step solutions (Doleck et al., 2017); (3) Pattern Recognition, which helps identify trends and relationships within data (Csizmadia et al., 2015); and (4) Abstraction, which focuses on extracting meaningful information to develop generalizable solutions (Csizmadia et al., 2015).

Science education plays a vital role in equipping future elementary school teachers with the knowledge and skills necessary for fostering scientific literacy among young learners. At the elementary level, science education emphasizes understanding natural phenomena and applying

scientific concepts to real-world problems. Given the dynamic nature of scientific knowledge, elementary school teachers must develop a strong foundation in science concepts (Dessty, 2016).

In teacher education programs, science courses cover various topics such as human-environment interactions, natural resources and energy, and applied science. Applied science, in particular, is highly dynamic and evolves with technological advancements. The curriculum includes subjects like food technology, simple biotechnology, electricity, and sustainable agriculture. These topics are designed to integrate physics, chemistry, and biology knowledge, providing pre-service teachers with a holistic understanding of science education.

Applied science courses encourage students to engage in hands-on learning experiences, fostering critical thinking and problem-solving skills. One effective pedagogical approach is Challenge-Based Learning (CBL) combined with Gamification, which has been successfully implemented in science courses (Nugraha, 2022). This model enhances student engagement by integrating interactive and problem-solving activities into the learning process.

The integration of computational thinking into science education is essential for preparing pre-service elementary school teachers. Science education inherently involves problem-solving, experimentation, and data analysis, all of which align with computational thinking principles. Ramlawati et al. (2019) argue that science process skills, such as observation, classification, interpretation, and prediction, play a crucial role in enhancing computational thinking abilities. By engaging in scientific inquiry, students develop logical reasoning skills that are fundamental to computational thinking.

Despite the potential benefits, research indicates that the integration of computational thinking in science education remains limited. Observations in teacher education programs reveal that many instructional practices fail to stimulate computational thinking. Key aspects such as lesson planning, implementation, student engagement, and real-world case studies are often overlooked, reducing opportunities for students to develop CT skills. This gap in learning may impact students' ability to formulate and understand scientific concepts effectively.

Preliminary assessments in science courses, such as "Human and the Environment," indicate that many students struggle with problem-solving tasks. Common issues include misconceptions about scientific quantities, difficulty in formulating solutions, inconsistencies in applying scientific formulas, and challenges in drawing logical conclusions. Without proper stimulation of computational thinking, students may lack the critical skills necessary for scientific reasoning and problem-solving.

It is crucial to incorporate computational thinking into science education for pre-service elementary school teachers to address these challenges. By doing so, teacher education programs can equip future educators with the cognitive skills required to navigate complex scientific and technological advancements. Additionally, integrating CT into science learning will enable teachers to foster similar skills in their students, ultimately enhancing STEM education at the elementary level.

The urgency of integrating computational thinking (CT) into science concept learning is increasingly critical in light of 21st-century demands, which emphasize higher-order thinking skills, digital literacy, and problem-solving abilities. These competencies are not only essential in the field of information technology but are also highly relevant for equipping students to understand and address complex and dynamic scientific challenges. As stated by Grover and Pea (2013), computational thinking is a key cognitive skill that underpins success in STEM learning, as it helps students approach problems logically and systematically. Furthermore, Shute et al. (2017) emphasize that the integration of CT in learning not only enhances technical skills but also facilitates the development of critical, collaborative, and creative thinking—skills that are highly needed in the future workforce. Therefore, explicitly integrating CT into science concept learning will strengthen

the cognitive capacity of pre-service teachers in designing innovative and adaptive instruction that meets contemporary needs.

This study aims to analyze the learning of science concepts in the Natural Resources and Energy course and to describe the implementation of computational thinking skills integration into science concept learning within the same course.

To provide a more focused scope for this research, the following research questions are formulated:

1. How is science concept learning implemented in the Natural Resources and Energy course?
2. How is the integration of computational thinking skills implemented in science concept learning within the Natural Resources and Energy course?

3. Methodology

3.1. Research Model

This study employs a descriptive quantitative approach. The aim of this research is to provide an overview of field facts related to the research object using numerical data and statistical analysis. The survey method was used in this study. This method is applied to analyze the optimization of science learning in integrating computational thinking skills within the Natural Resources and Energy course.

3.2. Participant/Sample

This study involved 198 elementary school teacher education students. It employed purposive sampling (Cresswell et al., 2003), a technique chosen because the selected participants had direct experience attending the natural resources and energy science concepts course. This method ensures that the subjects were relevant to the research objectives and provided in-depth information.

3.3. Data Collection Method

Data collection was conducted using two primary instruments: questionnaires and observation sheets. The questionnaire method involved a series of questions designed to gather students' perceptions regarding the implementation of the natural resources and energy course in developing computational thinking skills. The questionnaire used in this study consisted of 28 items with four answer choices representing four aspects. The questionnaire was developed by the research team and has been validated by experts in the fields of evaluation and measurement, language, and science education. In addition, this study also employed an observation technique. This technique was used to observe human behavior, work processes, and natural phenomena, as well as in research involving a limited number of respondents (Sugiyono, 2010). The aspects observed during the classroom observation consisted of four components: lesson planning, lesson implementation, student engagement, and lesson closure. Observations were conducted over the course of 12 class meetings.

3.4. Data Analysis

Instrument validity was tested through content validation by educational experts to ensure alignment between question items and the measured concepts (Cresswell et al., 2003). Construct validity was evaluated using confirmatory factor analysis with SmartPLS, yielding values of R-square = 0.296, SRMR = 0.111, and NFI = 0.493, indicating a good model fit. Reliability testing, conducted using Cronbach's Alpha, produced a value of 0.92, demonstrating a high level of instrument reliability. Setelah pengambilan data dilakukan maka dilanjutkan untuk analisis data. Data were analyzed using descriptive statistical analysis. This study collected complex information and presented it in a summarized form that is easier to understand.

4. Results

4.1. Observation of Science Concept Learning in the Natural Resources and Energy Course

Based on the observations conducted during the implementation of science concept learning in the natural resources and energy course within the elementary school teacher education program, four aspects were evaluated: lesson planning, lesson implementation, student engagement, and closing activities. The results obtained from these observations are presented in Figure 1.

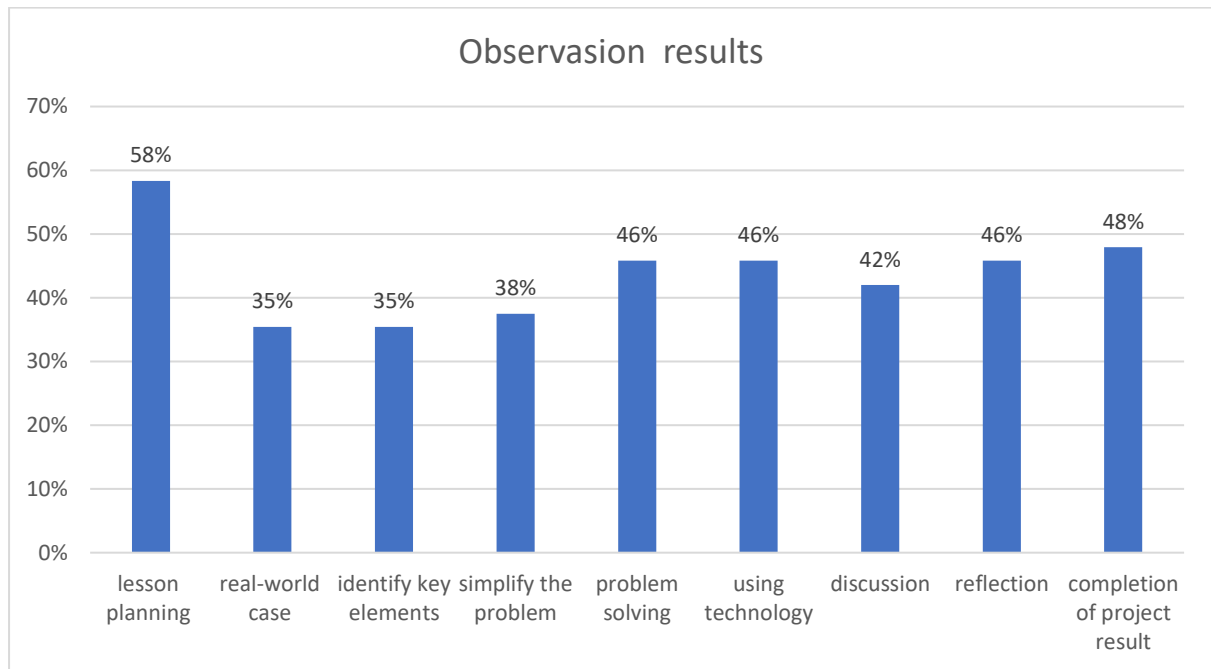


Figure 1. Observation Results of the Natural Resources and Energy Course

As illustrated in Figure 1, the observation results indicate that the lesson planning aspect was well-structured, with learning objectives scoring 58%. This suggests that the learning process in the natural resources and energy course was well-directed, with clear and measurable goals. However, within the same aspect, the sub-aspect concerning real-world case integration only scored 3%, indicating that real-world cases were not yet optimally integrated into the learning process. In the lesson implementation aspect, sub-aspects such as problem-solving and using technology remained suboptimal, each scoring 46%. The ability to identify key elements scoring 35% and simplify the problem 38%, yet it still requires further optimization to ensure high-quality learning. These findings suggest that the existing learning strategies have not sufficiently facilitated science concept learning. For the student engagement aspect, class participation was not yet considered satisfactory, with student engagement in technology use and discussion activities scoring less than 50%. This data suggests that the applied learning strategies did not effectively stimulate student engagement, as they provided limited opportunities for discussions and the integration of technology in the learning process. In the closing activities aspect, the sub-aspect of reflection scored 46%, while project completion achieved 48%. These results indicate that the learning process lacked sufficient space for reflection, and the relatively low project completion rate (below 50%) suggests that students' motivation to complete tasks still needs improvement.

4.2. Questionnaire on the Integration of Computational Thinking Skills into the Science Concept Learning in the Natural Resources and Energy Course

The integration of computational thinking skills in the learning of science concepts in the natural resources and energy course can be observed from the facilitation of the four computational thinking

aspects: decomposition, pattern recognition, abstraction, and algorithm. An effective learning process that stimulates computational thinking skills must accommodate all four aspects within the conducted lessons. Table 1 shows the questionnaire results on the implementation of computational thinking Skills Integration into the Science Concept Learning in the Natural Resources and Energy Course.

Table 1. Questionnaire Results on the Implementation of Computational Thinking Skills Integration into the Science Concept Learning in the Natural Resources and Energy Course.

Computational Thinking Aspect	Indicator	Achievement
Decomposition	Students can identify key elements of the material being studied.	56%
	Students can break down learning steps or tasks in the Natural Resources and Energy (NRE) course into smaller parts.	49%
Pattern Recognition	Students can identify recurring patterns in the structure of learning tasks.	46%
	Students can recognize patterns in the learning problems they encounter.	47%
Abstraction	Students can identify the core problem in the learning material or case studies.	40%
	Students can eliminate irrelevant information when completing assignments.	34%
Algorithm	Students can create a logical sequence of steps to complete tasks or learning projects (practical work).	40%
	Students can follow structured steps or procedures in solving learning problems.	50%

Based on the collected data, pre-service elementary school teachers still lack sufficient skills in the decomposition aspect. This is evident from the questionnaire results, which indicate that only 56% of students were able to identify key learning elements, and only 49% were able to break down tasks into smaller parts. This finding suggests that the learning process in the natural resources and energy course has not provided adequate support for developing students' computational thinking skills in decomposition.

The collected data show a similar trend for pattern recognition. The teaching strategies employed in the natural resources and energy course have not adequately facilitated computational thinking skills in this area. This is reflected in the two indicators: 46% of students were able to identify recurring patterns, and 47% were able to recognize patterns in learning problems.

The abstraction aspect also shows a low level of competency. The results indicate that only 40% of students could identify the core problem in the learning material, while only 34% were able to filter out irrelevant information when working on assignments. These findings demonstrate that the current teaching strategies in the natural resources and energy course have not effectively supported the development of computational thinking skills in abstraction.

For the algorithm aspect, the collected data indicate that this skill is also not well-facilitated in the learning process. The results show that only 40% of students could construct a logical sequence to complete tasks, and 50% were able to follow structured procedures in solving learning problems.

Overall, these findings suggest that the current teaching strategies in the natural resources and energy course have not successfully facilitated the computational thinking skills of pre-service elementary school teachers. The integration of computational thinking skills into the learning of science concepts remains low. Therefore, improvements are needed in various areas, particularly in lesson planning, implementation, and the incorporation of real-world case studies, to better stimulate computational thinking skills.

5. Discussion

5.1. Integration of Computational Thinking into Science Concept Learning in the Natural Resources and Energy Course

The results presented in Section 4.1 indicate that integrating computational thinking (CT) into science concept learning positively impacts the conceptual understanding of pre-service teachers. Meanwhile, Section 4.2 reveals that the CT-based learning approach enhances students' active engagement in learning and encourages them to think critically and systematically in solving problems. These findings are in line with the research of Grover and Pea (2013), who state that CT is a crucial cognitive skill underpinning success in STEM education, as it helps students think logically and systematically when addressing problems. Furthermore, Shute et al. (2017) emphasise that integrating CT into learning improves technical skills and fosters the development of critical, collaborative, and creative thinking skills highly needed in the future workforce.

Unlike this study, which focuses on pre-service teachers, research by Sáez-López et al. (2019) demonstrated that integrating CT through tools such as mBot among elementary school students can enhance their understanding of mathematics and science. This suggests that CT integration is effective across various educational levels, although the approaches and tools used may differ depending on students' educational level and needs. Another notable difference lies in the cultural and curricular context. A study by Cheng et al. (2023) found that CT integration in STEM education tends to be more effective in countries with integrated curricula and collaborative learning approaches. This highlights that the success of CT integration depends not only on instructional methods but also on systemic support from the curriculum and the local educational culture.

The integration of computational thinking skills into science concept learning in the natural resources and energy course within the elementary school teacher education program can serve as a means to stimulate other 21st-century skills among students. As Zhang and Wong (2023) stated, computational thinking is closely related to other cognitive functions such as logical thinking, critical thinking, procedural thinking, reasoning, and creativity. Based on the collected data, some aspects have shown promising results, particularly in lesson planning and defining learning objectives. However, other aspects remain underdeveloped, such as student engagement, reflection, problem-solving, and, most notably, the use of real-world cases in learning, which had the lowest percentage. These findings indicate that the current teaching strategies have not effectively facilitated computational thinking skills.

Learning activities must be grounded in real-world cases to successfully integrate computational thinking skills. This is essential because students will encounter real-life problems in their daily lives and need to be accustomed to dealing with relevant, real-world scenarios. Computational thinking skills will greatly assist students in solving everyday problems. Román-González et al. (2019) highlighted that computational thinking skills can be applied to solving real-world or daily life problems.

Modern education must accommodate fundamental skills such as thinking skills, problem-solving, and literacy. Therefore, computational thinking skills must be embedded in every learning activity. Grover and Pea (2013) also stated that integrating computational thinking skills into education will help students develop the analytical and adaptive skills necessary in today's digital era, particularly in tackling complex and dynamic challenges. Moreover, the application of computational thinking in education can train students to solve problems efficiently and systematically. Students' success in problem-solving can also enhance their self-confidence (Rosadi, M. E., Wagino, W., Alamsyah, N., Rasyidan, M., & Kurniawan, M. Y., 2020: 48).

In the context of science concept learning, particularly in the natural resources and energy course, essential supporting elements such as scientific literacy play a crucial role. Scientific literacy requires a well-directed and precise logic to ensure that the scientific concepts being studied are fully understood by students. Rini, Hartantri, and Amaliyah (2021) emphasized that competence in scientific literacy focuses on how individuals approach scientific questions and challenges. This involves the use of logic, reasoning, and critical and creative analysis, making it essential to examine the characteristics of students' scientific literacy competencies. To achieve this goal, learning activities must integrate computational thinking skills to enhance students' logical and reasoning abilities when exploring science concepts. This aligns with the perspective that computational thinking skills support effective logical problem-solving (Jamalludin, J., Muddakir, I., & Wahyuni, S., 2022: 266).

5.2. The Impact of the Integration of Computational Thinking into Science Concept Learning in the Natural Resources and Energy Course

Based on the presented results, an overview of science concept learning in the natural resources and energy course and its impact on aspects of computational thinking skills among pre-service elementary school teachers was obtained. Findings from observational data indicate that the aspect of determining learning objectives achieved the highest percentage, at 58%, while the use of real-world cases was only 35%. In the identify key elements and simplify the problem each reached less than 40%, as did case resolution. In terms of student engagement, the use of technology and discussions each scored 46% and 42%, indicating a relatively high level of participation. The closing activities stage, which includes reflection, had a percentage of 46%, while finalizing project results reached 48%. These data indicate that most aspects remain relatively low, particularly in the use of real-world cases in learning implementation. The inclusion of real-world cases in science learning activities is crucial, as the expected outcomes of learning extend beyond mere memorization of concepts to the acquisition of life skills applicable in daily problem-solving.

The main concept of education is closely related to the constellation of teaching and learning, as well as the handling of content that fosters understanding, enabling students to master both methods and competencies (Jonas, 2023). Mastery of methods and competencies encourages students to enhance their skill acquisition, so that they do not merely memorize concepts, but also develop true competence and practical skills. Students need to be provided with relevant and real cases to enhance their knowledge and experience in resolving issues (Fauzi, Ermiana, Rosyidah, & Sobri, 2022). Furthermore, presenting cases aligned with real-life situations can challenge students and encourage them to be more active in problem-solving (Wiranata & Sujana, 2021). Case-based learning can enhance students' problem-solving abilities by helping them understand the material and relate it to real-life situations (Daryanes et al., 2023). The case-based learning method encourages students not only to memorize concepts or content but also to develop competencies and skills—one of which is problem-solving. Additionally, based on the available data, planning and technological engagement play a vital role in supporting active and structured learning processes.

Questionnaire data show students' achievements in computational thinking skills, encompassing decomposition, pattern recognition, pattern generalization and abstraction, and algorithm. These aspects align with Brackmann et al. (2017), who identified four key components as the foundation of computational thinking skills: decomposition, pattern recognition, abstraction, and algorithmic design. These four components are considered pillars because they form the fundamental skills necessary for computational thinking (Diantary & Akbar, 2022).

In decomposition, the indicator of identifying key elements of the studied material scored 56%, while breaking down task steps into smaller parts scored 49%. These results indicate that both sub-aspects within decomposition remain low. Decomposition is a crucial pillar in enhancing students' computational thinking skills, as it allows complex or large problems to be broken down into smaller, more manageable parts (Rijke et al., 2018). Decomposition helps individuals break down complex data into simpler components. Shute et al. (2017) explain that decomposition is a cognitive approach that involves breaking down complex problems into more specific or smaller problems, making them easier to understand (Fried et al., 2019).

In pattern recognition, the indicator of identifying recurring patterns scored 46%, while recognizing patterns in encountered problems scored 47%. These results indicate that students are more capable of recognizing patterns than identifying recurring ones. However, the data suggest that both sub-aspects within pattern recognition remain low. Pattern recognition is essential in improving computational thinking skills, as it aids in structuring thought processes to identify solutions based on analyzed patterns. Anderson (2016) defines pattern recognition as the process of identifying repeated structures, patterns, or rules within a problem to develop more efficient solutions. This view is supported by Agbo et al. (2024), who state that pattern recognition involves identifying structures and relationships within or between problems.

In abstraction, the indicator of identifying the core of a problem scored 40%, while filtering relevant information scored 34%. These findings indicate that students are more capable of identifying core problems than filtering relevant information. However, both sub-aspects within abstraction remain very low. Abstraction is essential in computational thinking skills as it enables individuals to distinguish between relevant and irrelevant information, making it easier to develop solutions. Abstraction is the process of generalizing observed patterns by formulating general rules through the selection of relevant information while disregarding irrelevant details (Asbell-Clarke et al., 2021). Labusch et al. (2019) describe abstraction as eliminating unnecessary details and focusing on essential aspects, which allows for simplified solutions (Cansu & Cansu, 2019, p. 4).

In algorithm aspect, the indicator of following structured procedures scored 50%, while independently formulating logical steps scored 40%. These results indicate that students are better at following predefined procedures but still need development in abstract thinking and independent problem-solving. Algorithm aspect is crucial in mastering computational thinking skills as it involves structuring steps to solve problems. Algorithm design is defined as the process of creating a structured sequence of steps to develop solutions (Anderson, 2016). Hsu et al. (2018) support this view, stating that algorithm design involves formulating structured instructions to solve problems. Therefore, the algorithm aspect is essential for systematically outlining problem-solving steps.

5.3. Implementation of Computational Thinking in Science Concept Learning in the Natural Resources and Energy Course

Data indicate that the current implementation of science concept learning in the natural Resources and energy course is less effective in developing computational thinking skills due to several key reasons. First, science concept learning has been overly focused on achieving learning

objectives while neglecting the essence of scientific learning, which is the application of scientific principles in real-world contexts. The data show that the integration of real-world cases in learning is still very low, which contradicts the essence of science education. Desstya (2016) states that science education applies scientific knowledge to address practical issues in a broad and dynamic manner. This definition implies that learning science concepts should not only facilitate the understanding of concepts but also develop life skills, including computational thinking skills, which will be essential in the professional lives of future teachers. Odden et al. (2019) explain that, to use programming effectively, students must also possess certain knowledge related to how computation is applied in science. However, knowledge alone is not sufficient to develop computational thinking abilities, as computational thinking requires skills in analyzing various data to create the most effective solutions. As stated by Jacob & Warschauer (2018), analysis involves the reflective determination of whether abstraction and automation are correct. The science process skills, particularly the skill of analysis, if not properly facilitated, will certainly impact the application of scientific principles, which in turn affects computational thinking abilities.

Second, the use of ineffective teaching models has resulted in inadequate facilitation of skills such as problem-solving, reflective thinking, and other scientific skills. Consequently, student participation has not been optimal due to the lack of stimulation and facilitation from the teaching model. The essence of a teaching model lies in its role in structuring lesson materials, guiding classroom learning processes, and shaping curriculum implementation. Harefa et al. (2022) emphasize that a teaching model serves as a framework for designing lesson content, directing classroom learning, and structuring curricula. Thus, effective instructional strategies should be employed to equip students with 21st-century life skills, including computational thinking skills. Dalyono (2012) supports this view, stating that a teaching model is a structured set of steps designed to achieve learning outcomes effectively and efficiently.

Third, monotonous teaching methods have hindered discussion activities in higher education settings, resulting in suboptimal learning experiences. This issue stems from a teacher-centered learning approach. Discussions play a crucial role in higher education, particularly in fostering communication skills essential for articulating thought processes. This is as Nurwulandari et al. (2024) explain that presentation exercises, group discussions, and debates help learners refine their communication skills. Another impact of this situation is that students' learning skills become limited to mechanistic aspects. Nugroho (2022) states that most students at all levels still tend to engage in short-term thinking (short-term memory), merely referring to information without processing it (recite), restating it (restate), and relying on memorization (recall). This way of thinking remains confined to routine and mechanical aspects (Sundahry, Fitria, & Rakimahwati, 2018). Nevertheless, knowledge of information is also essential for developing computational thinking skills (Odden et al., 2019). Therefore, appropriate teaching methods are needed to foster computational thinking skills, as explained by Barcelos et al. (2018), who state that various teaching methods, such as CAD software, Java, and learning objects, can help develop computational thinking skills.

Furthermore, based on the data obtained regarding the integration of computational thinking skills in learning science concepts, it was found that computational thinking skills have not been maximally facilitated in science learning in the natural resources and energy course. This is evident in all aspects of computational thinking skills—including decomposition, pattern recognition, abstraction, and algorithms—which remain below 50%. Therefore, an appropriate learning model is needed to stimulate each aspect of computational thinking skills in learning science concepts. Essentially, meaningful science concepts lie at the intersection of theoretical reasoning and real-world scientific phenomena (Nugraha, 2022). Thus, science learning must be presented with real-life cases that occur in everyday life. The learning model that should be used is one that incorporates real-life cases into classroom learning. These real-life cases represent complex situations based on

actual conditions to encourage class discussions and collaborative analysis (Dharmayanthi, 2023). Case-based learning requires students to practice exploring and solving problems derived from the given case scenarios (Puspita & Dwikoranto, 2020).

The integration of real-life cases into the learning model can stimulate students' computational thinking skills. According to Xu et al. (2022), computational thinking is a cognitive skill rooted in computer science that can be applied to solving various problems. Piatti et al. (2022) explain that computational thinking involves three main processes: (a) defining problems within a specific context so that the solutions can be computed, (b) designing and representing algorithms to be implemented by agents, whether human or artificial (such as computers), and (c) evaluating the quality of solutions through an assessment process. Therefore, to enhance students' computational thinking skills, a learning model that incorporates real-life cases into the learning process is necessary to stimulate all aspects of computational thinking skills. Through their research, Yang et al. (2024) used a blended contextual teaching model via an e-learning platform combined with real-life scenarios to create specific real-world situations, successfully encouraging students to engage in rich thinking activities, improving academic performance, and enhancing their computational thinking abilities. Similarly, the research by Xu et al. (2019) successfully developed students' computational thinking skills through the case-based teaching method.

6. Conclusion

This study found that science concept learning in the natural resources and energy course has not yet been optimal in integrating computational thinking skills. The data indicate that only the learning objectives sub-aspect in the planning stage is categorized as good, while the rest are still relatively low—even the real-world case presentation sub-aspect remains very low. Real-world cases are one of the best stimuli for developing fundamental skills related to science concept learning. Thus, the natural resources and energy course still requires significant improvements. Learning innovations must be implemented, particularly in teaching strategies, instructional materials, and collaborative spaces among students. These findings suggest that further and more systematic efforts are needed to enhance the computational thinking skills of pre-service elementary school teachers. Strengthening these skills is crucial to better prepare them for the challenges of working as elementary school teachers. The data obtained in this study are limited to the perspectives of the participants involved. It is assumed that the participants responded sincerely to the quantitative data collection tools used in the study.

7. Suggestion

Future research is recommended to focus on developing strategies for integrating computational thinking skills, particularly in the field of science. The right strategies will be able to provide solutions for creating a more supportive learning environment for the integration of computational thinking skills in the learning of science concepts in the Natural Resources and Energy course. The development of learning models to stimulate computational thinking skills should be prioritized in future research advancements. Moreover, further research should explore the role of constructive and reflective feedback in actively engaging students and improving the quality of science concept learning. A deeper investigation into educators' understanding of individual differences in the classroom and the application of appropriate teaching methods is also essential for enhancing computational thinking skills in a more extensive and holistic manner.

Declarations

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