Enhancing Pre-Service Physics Teachers' Knowledge in Designing 4C-Oriented Problem-Based Learning through an Interactive Reading Strategy with Electronic Learning Materials

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Abstract. This study aims to investigate the effectiveness of an interactive reading strategy supported by electronic learning materials in improving pre-service teachers' knowledge in designing physics instruction based on a 4C-oriented PBL model. This study employed a pre-experimental design with a one-group pretest–posttest approach. The participants were 24 pre-service physics teachers enrolled in a physics teaching planning course in a physics education program. Data were collected using multiple-choice knowledge tests administered before and after the intervention, as well as interview sheets. The data were analyzed using descriptive statistics, Rasch model analysis, and normalized gain (N-gain) to determine the level of improvement. The results indicate that the implementation of the interactive reading strategy supported by electronic learning materials significantly improved students' knowledge in designing 4C-oriented PBL instruction. The mean posttest score was higher than the pretest score, with an N-gain value of 0.82, categorized as high. In addition, the distribution of knowledge levels shifted substantially from low and very low categories before the intervention to high and very high categories after the intervention. These findings suggest that the integration of interactive reading strategies with electronic learning materials is effective in facilitating self-regulated learning and strengthening instructional design competence. This approach can be considered an alternative strategy to support the development of pre-service teachers' pedagogical knowledge, particularly in designing physics instruction aligned with 21st-century skills.
Keywords: Interactive Reading, Electronic Learning Materials, Problem-Based Learning, 4C Skills, Pre-Service Physics Teachers.

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1. Introduction

The rapid development of science and technology in the 21st century has had significant implications for education, particularly in preparing students with essential competencies known as 4C skills. The 4C skills: critical thinking, communication, collaboration, and creativity and innovation are essential for students, as they enable not only adaptation to change but also the capacity to act as agents of change. Students who possess critical thinking skills are able to filter information more selectively, distinguish between valid information and misinformation, and make decisions based on available alternatives. Strong communication skills enable students to effectively express ideas and arguments,

which is a key factor for success in the workplace. In addition, creative thinking skills contribute to the development of innovative products that address various problems, including limitations in infrastructure and natural resources. Meanwhile, collaboration skills are essential for building partnerships and networks in the 21st century. The 4C skills are not innate abilities but are developed through life experiences, both in formal education and in professional environments (Dilekçi & Karatay, 2023; Radifan & Dewanti, 2020). Training in 4C skills can be implemented across various disciplines, including physics education (Setiawati et al., 2020; Viyanti et al., 2021).

The 4C skills are highly relevant to the characteristics of physics as a subject, which requires students to think systematically, structurally, and creatively (Novitra et al., 2021; Viyanti et al., 2021). In efforts to develop 21st-century competencies through physics education, the Indonesian government, through the 2013 Curriculum and the Merdeka Curriculum, mandates the use of student-centered learning models such as Problem-Based Learning (PBL). Through active and interactive learning approaches, students are trained to develop critical thinking skills by analyzing information, evaluating various solutions, and drawing logical conclusions. Problem-solving activities encourage students to generate creative solutions to challenges they encounter, while communication and collaboration skills are developed through teamwork, idea sharing, and effective interpersonal interaction. Furthermore, creativity and innovation enable students to generate new ideas that are applicable to real-life contexts.

PBL is a learning model in which students engage in solving real-world problems without prior structured preparation, relying on sufficient prior knowledge to address the problem. This requires students to expand their existing knowledge and understanding while working collaboratively in groups. Learning is facilitated by a tutor or teacher, and students apply the knowledge they acquire to produce solutions to the given problems (Moallem et al., 2019; Tefera et al., 2024). A key characteristic of PBL is that the problems presented are ill-structured and do not have a single correct solution, thereby encouraging students to formulate questions and seek additional information.

For the effective integration of 4C skills in physics learning, teachers must possess adequate knowledge and skills in designing instruction that supports these competencies (Aidoo, 2023; Darling-Hammond et al., 2017; Shulman, 1987), including pre-service teachers. This competency is essential for both in-service teachers and pre-service teachers in order to design effective learning experiences that prepare future generations to compete in an increasingly complex global era.

However, preliminary evidence from universities in West Kalimantan, obtained through a knowledge assessment on 21st-century learning characteristics, 4C skills, 4C-oriented instructional design, and the Problem-Based Learning (PBL) model, indicates a concerning gap in pre-service teachers' understanding. Data collected from 99 pre-service physics teachers (see Figure 1) reveal that their knowledge remains at a low level, particularly in relation to 4C skills and PBL (Nurhayati et al., 2025). This gap is critical, as these competencies are essential for preparing students to meet the demands of 21st-century learning.

This finding is consistent with prior research by Varas et al. (2023), which highlights that both in-service and pre-service teachers possess limited knowledge of 4C skills and encounter difficulties in integrating, implementing, and assessing these skills in classroom contexts. Therefore, there is a clear need for targeted interventions to enhance pre-service teachers' knowledge and capacity in designing 4C-oriented learning environments.

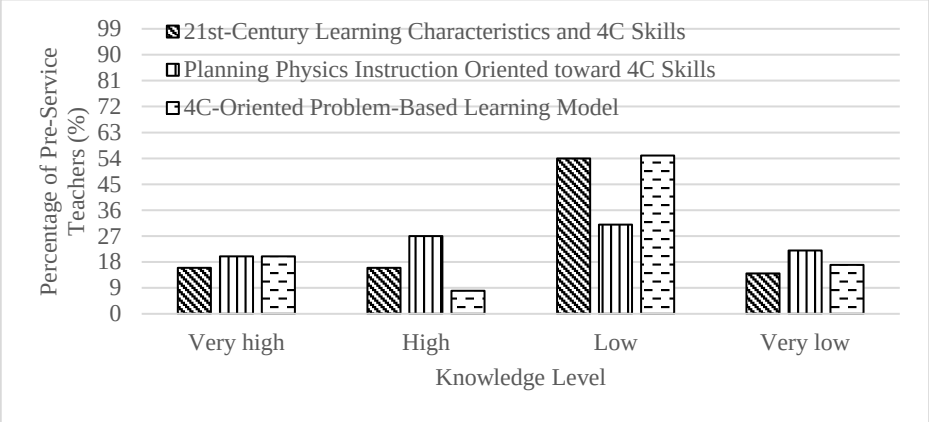

Figure 1. Percentage Distribution Chart of Students at Each Knowledge Level

One potential instructional strategy is the use of an interactive reading strategy supported by electronic learning materials. Interactive reading encourages active engagement with learning content through questioning, reflection, and discussion. When combined with electronic learning materials, this strategy provides flexible access to structured content, enabling students to learn independently while still receiving guidance through well-designed instructional resources. Electronic learning materials also facilitate the integration of multimedia elements, which can enhance understanding of abstract physics concepts and principles of instructional design.

An interactive reading strategy is considered an effective approach for independent learning to develop students' deep understanding of instructional content. In interactive reading activities, students do not merely read texts passively; instead, they are actively involved in interacting with the text. They are encouraged to ask questions, make predictions, and reflect on the reading material. Such interactions strengthen conceptual understanding and enhance students' ability to design instruction grounded in deep comprehension (Banditvilai, 2020). This approach is also consistent with constructivist theory, which emphasizes the importance of active engagement in the learning process to deepen learners' understanding of the material. A study by Shao et al. (2025) found that the implementation of an interactive reading strategy supported by electronic books can improve students' ability to analyze information, stimulate intrinsic motivation to learn, and strengthen interest and focus in learning.

Several studies have demonstrated that interactive learning strategies and digital materials can improve students' conceptual understanding and learning outcomes (Bahari et al., 2021; Cordero et al., 2015; Merga, 2017; Varol & Erçetin, 2021). However, limited research has specifically examined their role in enhancing pre-service teachers' knowledge in designing 4C-oriented PBL, particularly in physics education. This gap highlights the need for further investigation.

Therefore, this study aims to enhance pre-service physics teachers' knowledge in designing 4C-oriented PBL through an interactive reading strategy supported by electronic learning materials. The research questions are as follows: (1) How does the implementation of an interactive reading strategy supported by electronic learning materials improve prospective teachers' knowledge in designing physics instruction based on the 4C skill-oriented PBL model?; (2) How does the level of prospective teachers' knowledge change after the implementation of an interactive reading strategy supported by electronic learning materials?. The findings of this study are expected to contribute to the development of effective instructional strategies in teacher education and provide practical implications for improving the quality of physics instructional design.

2. Method

The research method employed in this study was a pre-experimental design using a one-group pretest–posttest approach (Fan et al., 2022; Little et al., 2019). This method was chosen because it allows the researcher to identify changes occurring before and after the treatment within a single group of participants, thereby providing an overview of the effectiveness of the implemented intervention.

The participants in this study consisted of 24 pre-service physics teachers from a physics education program at a university in West Kalimantan, Indonesia. The sampling technique used was purposive sampling, which allows researchers to deliberately select participants based on specific criteria relevant to the research objectives (Etikan, 2016; Palinkas et al., 2015; Wannenburg & Curlewis, 2023). Through this approach, the selected sample is expected to possess appropriate characteristics to provide in-depth information related to the phenomenon under investigation (Fitriati et al., 2024).

The research procedure consisted of three main stages: (1) administering a pretest to measure participants' initial knowledge in designing PBL instruction oriented toward 4C skills; (2) implementing an interactive reading strategy supported by electronic learning materials, which included guided reading activities, integrated questions, tasks, and feedback; and (3) administering a posttest to measure participants' knowledge improvement after the intervention.

Data were collected using a validated knowledge test focusing on instructional design aligned with 4C skills (critical thinking, creativity, collaboration, and communication), as well as interview guidelines. The instrument was developed based on specific indicators of PBL and 4C integration and met validity criteria based on expert judgment and reliability testing results.

Data analysis was conducted using descriptive and inferential statistics. Students' knowledge scores were transformed into logit units using Rasch model analysis (Nurhayati et al., 2025). The person logit values were then categorized into four levels: very high (VH), high (H), low (L), and very low (VL), for both pretest and posttest data. Subsequently, the pattern of changes in students' knowledge levels before and after the intervention was analyzed. The improvement in participants' knowledge was also examined using the normalized gain (N-gain) score, which was classified into high, medium, and low categories.

3. Results and Discussion

Improvement in Pre-Service Teachers' Knowledge in Designing Physics Instruction Based on the 4C-Oriented Problem-Based Learning (PBL) Model

The results of the study indicate that students' knowledge in designing Problem-Based Learning (PBL)-based instruction oriented toward 4C skills significantly improved after the implementation of an interactive reading strategy supported by electronic learning materials. The data presented in Table 1 show that, following the intervention, students' knowledge was categorized as high. This improvement is further supported by an N-gain value of 0.82, which falls within the high category. These findings suggest that the interactive reading strategy supported by digital learning materials, which emphasizes active learning and effective use of technology, is capable of facilitating students' understanding in designing 4C-oriented PBL instruction. This strategy not only positions students as passive readers but also encourages active engagement through interaction with texts and collaborative discussion with peers (van Laar et al., 2020; Voogt & Roblin, 2012).

Table 1. Description of Students' Knowledge Data

Data Description	*Pre-test*	*Posttest*
Number of Data (N)	24	24
Maximum Score	42	67
Minimum Score	10	54
Ideal Maximum Score	70	70
Mean Score	33,17	63,13
Standard Deviation	8,34	3,49
N-Gain	0,82	
Improvement Category	High	

From a constructivist perspective, these findings indicate that the learning process enables students to actively construct knowledge through interaction with learning resources and meaningful learning experiences (Bruner, 1961). Within this framework, knowledge is not directly transmitted but is instead built through processes of interpretation, elaboration, and collaboration (Moyer et al., 2016). The interactive reading strategy employed in this study facilitates this knowledge construction process through active reading activities and reflective discussions (Nurhayati et al., 2026).

This improvement can also be explained through Self-Regulated Learning (SRL) theory, in which students have control over their learning processes, including the regulation of strategies, time management, and learning resources (Zimmerman, 2005). The integration of electronic learning materials within the interactive reading strategy provides flexibility that supports students in learning independently and in a structured manner (Broadbent & Poon, 2015; Fayaza & Ahangama, 2024). This is consistent with the finding that 96% of students were in the high improvement category, indicating the effectiveness of self-directed learning management in enhancing cognitive achievement (Prasse et al., 2024).

In addition, from the perspective of cognitive engagement, the strategy used in this study promotes high-level cognitive involvement through processes of analysis, evaluation, and synthesis of information. The interactive activities during learning enable students not only to understand concepts at a surface level but also to integrate these concepts into the context of designing 4C-oriented PBL instruction.

This improvement is not only evident in general terms but also specifically across each assessed topic. Based on Table 2, all three topics demonstrated high-category improvement, although the N-gain values varied. These topics include 21st-century learning characteristics and 4C skills, physics instructional planning oriented toward 4C skills, and the 4C-oriented PBL model. This further confirms that the implemented strategy is consistently effective across different content domains.

Table 2. Improvement in Students' Knowledge of Designing Physics Instruction Based on the 4C-Oriented PBL Model

No	Material	*Mean pre-test*	*Mean posttest*	Ideal Maximum Score	N-Gain	Category
1	21st-Century Learning Characteristics and 4C Skills	8,58	22,88	25,00	0,88	Tinggi

No	Material	*Mean pre-test*	*Mean posttest*	Ideal Maximum Score	N-Gain	Category
2	Planning Physics Instruction Oriented toward 4C Skills	13,63	22,58	25,00	0,79	Tinggi
3	4C-Oriented Problem-Based Learning Model	10,96	17,67	20,00	0,74	Tinggi

At the individual level, 96% of the students experienced a high category of knowledge improvement, while 4% were in the medium category (Figure 2). These findings indicate that nearly all students demonstrated an improvement in knowledge following the learning process.

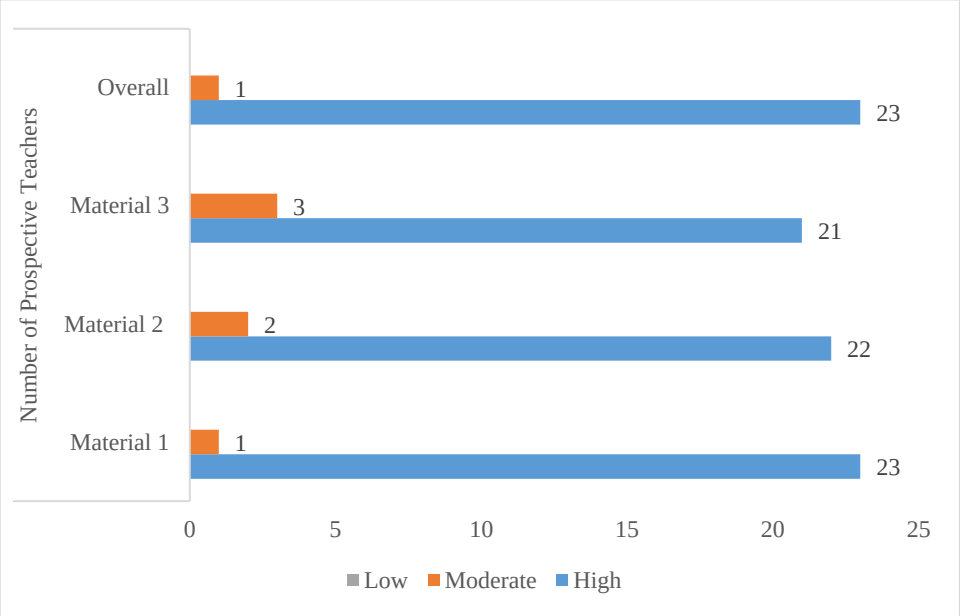

Figure 2. Pre-Service Teachers' Knowledge Improvement Across Each Topic

The observed improvement is closely related to the characteristics of independent learning integrated into the instructional strategy. Independent learning is an approach that assigns responsibility to students for managing their own learning processes, including determining strategies, time allocation, and learning resources. This aligns with SRL theory, which emphasizes the importance of self-control in the learning process to achieve optimal outcomes.

The findings of this study also indicate that students were able to effectively manage their learning process through an interactive-based learning strategy, which contributed to improved conceptual understanding. This finding is consistent with Botha et al. (2025) and Scheel et al. (2022), who state that self-directed learning empowers learners to become more mature and independent, thereby enhancing deeper understanding of learning content. In addition, self-regulated learning has also been shown to be a strong predictor of academic performance (Gupta et al., 2024; Scheel et al., 2022).

The interactive reading strategy focuses on active student engagement with the learning text rather than passive reading. In this context, students are not only required to comprehend the content but also to engage in various activities such as discussion, critical analysis, and reflection. This is consistent with findings indicating that interactive learning combined with digital media is effective in deepening conceptual understanding (Gupta et al., 2024).

The use of technology and digital learning materials also provides flexibility for students to access content according to their individual learning pace and needs. In addition to enriching the learning experience, the integration of technology enables a more dynamic and interactive learning process. This finding is consistent with previous studies showing that active learning involving direct student participation is more effective than passive, lecturer-centered instruction (Botha et al., 2025; Christanti & Sukoco, 2022; Hockings et al., 2018).

In this context, interactive reading supported by digital learning materials not only facilitates individual text comprehension but also promotes collaboration and the exchange of ideas among students. This process enables deeper knowledge elaboration, broader perspectives, and the integration of learned concepts (Rui et al., 2024). Thus, this strategy contributes to strengthening conceptual understanding in designing 4C-oriented PBL instruction.

Patterns of Changes in Pre-Service Teachers' Knowledge Levels in Designing Physics Instruction Based on the 4C-Oriented Problem-Based Learning (PBL) Model

The results of the study show variations in the improvement of students' knowledge levels in designing PBL instruction oriented toward 4C skills after the implementation of an interactive reading strategy supported by digital learning materials. In general, students' knowledge levels prior to instruction were categorized as "low" and "very low," whereas after the intervention they improved to "high" and "very high" (Figure 3). This change indicates the effectiveness of the intervention in enhancing pre-service teachers' knowledge in designing learning based on the PBL model oriented toward 4C skills.

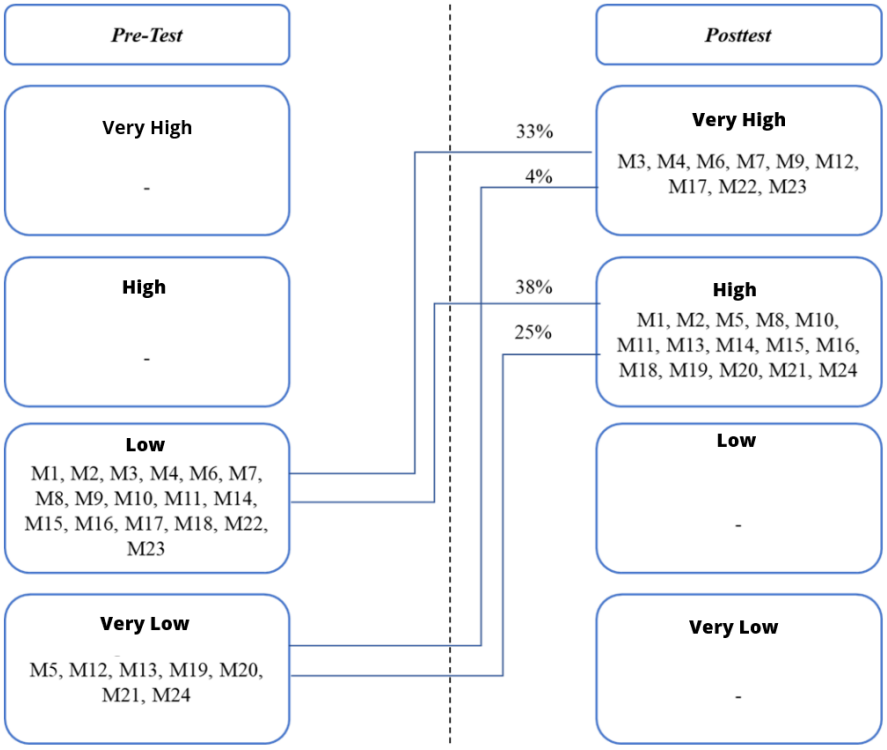

Figure 3. Patterns of Changes in Students' Knowledge Levels

In detail, 33% of students improved from the "low" category to "very high," 38% from "low" to "high," 4% from "very low" to "very high," and 25% from "very low" to "high." These differences

in improvement levels can be explained by variations in learning pace, motivation, and learning strategies used during the intervention process (Walker et al., 2024). Students who demonstrated higher improvement tended to show more rapid development of initial understanding through active engagement in the interactive learning process.

From a constructivist perspective, these findings indicate that knowledge is not passively transmitted but is constructed through active interaction with learning materials, learning experiences, and social discussion. The interactive reading strategy facilitates this knowledge construction process through active reading, analysis, and reflection activities. In line with this, the approach also reflects the principle of cognitive engagement, in which students are involved in higher-order thinking processes such as analysis, synthesis, and evaluation in understanding the concept of 4C-oriented PBL.

In addition, differences in achievement are also associated with aspects of SRL. Students with higher levels of improvement demonstrated better abilities in regulating their learning processes, including strategy planning, comprehension monitoring, and self-evaluation. This is reflected in their tendency to participate in multiple testing opportunities as a form of reflection and learning improvement. This finding is consistent with Hamza et al. (2025), who show that a combination of high motivation, strategic awareness, and time management contributes to consistent improvements in academic performance.

Intrinsic motivation is also an important factor influencing these differences in achievement. Students with higher intrinsic motivation tend to be more active in exploring learning materials, asking critical questions, and striving to understand concepts in depth. This finding is consistent with (Walker et al., 2024), who report a positive relationship between motivation and learning outcomes.

Furthermore, the learning environment also influences student learning outcomes. Loyens et al. (2008) and Scheel et al. (2022) emphasize that the effectiveness of self-directed learning is influenced by both learner characteristics and learning environment conditions. In this study, technical constraints such as unstable internet access were identified as limiting factors in optimizing self-directed learning, as they hindered access to digital learning materials.

Interview findings confirmed that these access limitations affected students' learning time. This indicates that the success of self-directed learning does not depend solely on internal learner strategies but also on environmental support. Pradhan, S. (2021) emphasizes that self-directed learning can still pose challenges even for highly motivated students when it is not supported by adequate learning resources and access.

In this context, the independent learning materials (Bahan Belajar Mandiri/BBM) used in this study were designed interactively to address these limitations. The BBM includes interactive features such as guiding questions, integrated text, videos, images, and additional references accessible via links and QR codes. The use of a flipbook application further enhances accessibility and visual attractiveness, thereby supporting student engagement.

The quality of this instructional design aligns with the constructivist learning environment framework, in which students are encouraged to construct understanding through active exploration. This is supported by Botha et al. (2025) and Rui et al. (2024), who emphasize that effective self-directed learning requires instructional design that supports reflection, autonomy, and self-evaluation.

Moreover, the structured design of the BBM, which begins with learning outcomes, indicators, and learning guidelines, provides clear direction for students in managing their learning process

(Nurhayati et al., 2026). This clarity helps reduce confusion and improves the organization of independent learning (Gupta et al., 2024). This is also consistent with Koňušíková & Kostelník (2009), who highlight the importance of guided self-directed learning in achieving optimal learning outcomes.

Another aspect supporting the effectiveness of the learning process is the presentation of an introductory video as an initial stimulus that connects the learning material to real-world contexts. This strategy enhances students' motivation and learning readiness. Furthermore, the interactive presentation of learning content with guiding questions strengthens cognitive engagement and helps students connect theoretical concepts with practical applications (Banditvilai, 2020; Freeman et al., 2014).

In addition, the provision of tasks based on links and QR codes offers flexible access that supports the principles of independent learning. Students can access learning materials anytime and anywhere, thereby enhancing learning autonomy (Minard, 2024). The designed tasks also promote higher-order thinking skills such as analysis and problem-solving (Lu, 2025; Schmid et al., 2023).

Collaborative learning in task completion also strengthens the social dimension of learning, in accordance with Vygotsky's social constructivist theory. Peer-to-peer interaction has been shown to enhance confidence and improve the effectiveness of decision-making (Keenan, 2014; Rowe et al., 2021; Rui et al., 2024). Thus, learning is not only an individual process but also a socially collaborative one.

The findings of this study indicate that the integration of an interactive reading strategy supported by digital learning materials within a self-directed learning framework can significantly improve students' knowledge. This effectiveness is supported by the synergy of constructivism, self-regulated learning, and cognitive engagement, which operate simultaneously throughout the learning process.

4. Conclusion

The implementation of an interactive reading strategy supported by electronic learning materials has been proven effective in improving prospective teachers' knowledge in designing physics instruction based on the 4C-oriented Problem-Based Learning (PBL) model. This improvement is indicated by a significant increase in knowledge scores and a high category of normalized gain. In addition, there is a clear shift in knowledge levels, from predominantly low and very low before the intervention to high and very high after the intervention, reflecting improvements in both quantitative outcomes and the overall quality of understanding.

The findings imply that integrating interactive reading strategies with electronic learning materials is a promising approach to supporting the development of prospective teachers' competencies in designing 21st-century learning. This approach also enhances student engagement and facilitates deeper conceptual understanding through the use of digital technology.

Future studies are recommended to examine this approach using more rigorous experimental designs and in broader contexts, as well as to investigate its direct impact on 4C skills. Furthermore, adequate technological support and well-designed learning materials should be considered to ensure effective implementation.

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