



Designing digital teaching materials for meaningful science instruction: Enhancing pedagogical competence in elementary education

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ABSTRACT

Article History

Received: 16 February 2026

Revised: 27 April 2026

Accepted: 18 May 2026

Published: 9 October 2026

Keywords

Deep learning
Digital teaching materials
Elementary education
Pedagogical competence
Tamansiswa-based learning.

Pedagogical competence is a fundamental requirement for ensuring effective and meaningful learning in elementary education. However, many teachers still experience difficulties in designing engaging science instruction supported by structured digital resources. This study aimed to develop and evaluate digital teaching materials grounded in a deep learning approach and enriched with Tamansiswa educational values to enhance teachers' pedagogical competence. The research employed a developmental design using the ADDIE framework: analysis, design, development, implementation, and evaluation. Data were gathered through interviews, observations, questionnaires, and pedagogical competence tests involving prospective and practicing teachers. Qualitative and quantitative descriptive analyses were applied to examine the product's feasibility, practicality, and effectiveness. The resulting materials emphasize meaningful, mindful, and joyful learning experiences while incorporating activities aligned with Tamansiswa principles such as observing, imitating, and innovating to support holistic learning processes. Expert validation indicated a high level of feasibility (83.5%), and practicality testing showed very strong usability (91.97%). Implementation results demonstrated a substantial improvement in teachers' pedagogical competence, with average scores increasing from 43.27 to 81.30 in limited trials and from 44.88 to 84.90 in broader implementation. These findings suggest that culturally grounded digital teaching materials can function as an effective bridge between technological integration and pedagogically sound science instruction in elementary classrooms.

Contribution/Originality: This study contributes to the existing literature by integrating digital instructional design with the Tamansiswa philosophy. This study uses a novel pedagogical alignment approach. This study is among the very few that have investigated culturally grounded digital materials. The paper's primary contribution is finding that such integration strengthens teachers' pedagogical competence.

1. INTRODUCTION

Teachers play a crucial role in achieving national education goals, requiring them to possess superior competencies, including personal, social, pedagogical, and professional competencies (Darling-Hammond, Schachner, Wojcikiewicz, & Flook, 2024). One of the competencies teachers must possess is pedagogical competence. This competency must be cultivated during their educational years, including elementary school teacher education.

The mastery of concepts possessed by teachers and prospective teachers is a requirement for carrying out the learning process. Pedagogical competence also has a very large role in implementing effective and efficient learning

so that learning objectives can be achieved properly. This competence is proven by the ability of teachers and prospective teachers to understand the characteristics of students, materials, and environment so that they are able to determine the right approach, model, method, strategy, and media to achieve learning objectives, and can create learning that is fun, interesting and able to develop the potential of students, the ability to utilize technology in learning, the ability to carry out assessments and evaluations in learning, and the ability to reflect on the learning that has been carried out (Qadrianty, Dollah, & Muliati, 2024; Tokić, Brčić, & Miočić, 2025; Wardoyo, Satrio, & Ratnasari, 2020). However, the results of the needs analysis conducted through observation indicate that the competencies possessed by teachers and prospective teachers are still relatively low. This is evidenced by the results of observations that prospective teachers still lack conceptual knowledge of learning design, learning models, and appropriate learning approaches to achieve learning objectives.

Interviews with science lecturers in the Elementary School Teacher Education Program also showed that 90% of respondents stated that prospective teachers' pedagogical skills were still relatively low. Interviews and classroom observations also revealed that prospective teachers frequently relied on generative artificial intelligence tools when searching for instructional information. Although such tools can facilitate rapid access to educational content, students often use them without critically evaluating or adapting the generated responses (Zou, Kuek, Feng, & Cheng, 2025). This pattern indicates the absence of structured instructional resources that guide prospective teachers in understanding pedagogical concepts and instructional design processes. Previous studies have emphasized that the effective integration of digital technologies in teacher education requires well-designed teaching materials that promote reflection, conceptual understanding, and pedagogical reasoning (Kim & Kwon, 2025). Therefore, the availability of structured digital teaching materials becomes an important component in supporting meaningful teacher learning. The learning process also lacks the integration of in-depth learning principles, a policy that needs to be implemented in the learning process, and the Tamansiswa teachings, a hallmark of the institution, have not yet been fully internalized.

An alternative solution that can be implemented to improve teachers' pedagogical competence is through innovation in digital teaching materials. Teaching materials are learning tools that help students achieve their learning goals independently. Criteria for good teaching materials (modules) include being stand-alone, self-instructive, self-contained, adaptive, and user-friendly (Fleming, 2024). The use of digital learning in this learning process was also chosen to adapt to the challenges of global digital developments while simultaneously simplifying student access to existing teaching materials and learning resources and increasing the effectiveness of learning (Tuia & Esera, 2023; Wijayanti, Dwiningrum, Saptono, & Maulyda, 2025; Zulfiani et al., 2025).

The developed teaching materials are designed with the principles of a deep learning approach, namely learning that honors by emphasizing the creation of a conscious, meaningful, and joyful learning atmosphere and process through holistic and integrated thought, heart, feeling, and exercise. This approach aims to develop a person's abilities in broader knowledge and skills (transferable skills) that can be applied in various subjects and contexts (Suyanto, 2025).

Principles of the deep learning approach are also highly relevant to the principles of Tamansiswa Teachings. The principles of Tamansiswa teachings were initiated by Dewantara (2013), the Father of Indonesian Education, and adapted to the philosophy of Indonesian education. These teachings are adapted to the distinctive socio-cultural characteristics of Indonesia. Some of these teachings include the system, leadership trilogy (ing ngarsa sung tuladha [leading by example], ing madya mangun karsa [inspiring and motivating others], tut wuri handayani [providing guidance and support from behind]), Tri-Nga (ngerti [understanding], ngrasa [feeling and internalizing], nglakoni [practicing or applying]), Tri-N (niteni [observing], nirokke [imitating], nambahi [adding to or improving]) (Dewantara, 2013; Nurmawati et al., 2022; Samho, 2013). This research innovation is used as an effort to participate in realizing the graduate profile in a deep learning approach, while also participating in realizing the dimensions of

the Pancasila student profile as stated in the independent curriculum implemented in higher education, so that it becomes a novelty in learning at the tertiary level, especially in science learning innovations in elementary schools.

Despite the increasing availability of digital learning resources in teacher education, many instructional materials remain fragmented and insufficiently aligned with the development of pedagogical competence (Zaqiah, Hasanah, Heryati, & Rohmatulloh, 2024). Existing studies tend to focus either on technological tools or on pedagogical training without systematically integrating both aspects within a structured instructional resource. In addition, limited attention has been given to incorporating local educational philosophies within digital instructional design, particularly in the context of elementary science learning. As a result, prospective teachers often rely on scattered online materials that do not provide coherent guidance for designing meaningful science instruction (Muammar & Muslimin, 2026).

Therefore, this study addresses this gap by developing and evaluating digital teaching materials that combine deep learning principles with Tamansiswa educational values. The research aims to examine whether such integrated materials can effectively enhance the pedagogical competence of prospective and practicing elementary school teachers.

2. LITERATURE REVIEW

2.1. *Pedagogical Competence in Elementary Education*

Pedagogical competence remains a central component of effective teaching, particularly in elementary education, where teachers are expected to translate abstract concepts into meaningful learning experiences. According to Mishra and Koehler (2006) pedagogical competence involves not only knowledge of subject matter but also the ability to transform that knowledge into forms that are accessible to learners. This concept, widely known as pedagogical content knowledge, highlights the integration of content, pedagogy, and learner understanding.

In practice, however, many prospective teachers struggle to operationalize pedagogical knowledge into classroom instruction (Muslimin, Mukminatien, & Ivone, 2022). Studies have shown that teacher candidates often demonstrate limited ability in designing learning activities, selecting appropriate strategies, and assessing student understanding. This indicates that pedagogical competence is not automatically developed through theoretical exposure alone but requires structured guidance and contextualized learning experiences.

Furthermore, recent empirical studies suggest that teacher-education programs frequently emphasize theoretical knowledge at the expense of practical pedagogical design (Nasiruddin & Sahril, 2018). As a result, prospective teachers may possess conceptual understanding but cannot implement it effectively in classroom settings. This gap underscores the need for instructional interventions that explicitly support the development of pedagogical competence through guided practice and reflective learning.

2.2. *Digital Teaching Materials in Teacher Education*

The integration of digital technology into education has transformed how instructional resources are designed and delivered (Herodotou et al., 2019). Digital teaching materials offer flexibility, accessibility, and opportunities for interactive learning, making them particularly relevant in teacher education contexts. These materials can support prospective teachers in exploring instructional strategies, visualizing abstract concepts, and engaging in self-paced learning.

Despite these advantages, the effectiveness of digital teaching materials largely depends on their design and structure (Area-Moreira, Rodríguez-Rodríguez, Peirats-Chacón, & Santana-Bonilla, 2023). Poorly organized digital resources may lead to fragmented learning experiences, where students access information without developing a coherent understanding of pedagogical principles. Research has shown that many digital resources used in teacher education are not systematically aligned with learning objectives or pedagogical frameworks.

Moreover, the increasing use of generative artificial intelligence tools has further complicated the landscape of digital learning (Lachheb, Leung, Abramenka-Lachheb, & Sankaranarayanan, 2025). While such tools can provide rapid access to information, they do not necessarily promote deep understanding or critical thinking. Without structured guidance, students may rely on surface-level information retrieval rather than engaging in meaningful learning processes. This reinforces the importance of designing digital teaching materials that guide learners toward conceptual understanding and pedagogical reasoning.

2.3. Deep Learning as a Pedagogical Approach

Deep learning, in the educational sense, refers to a learning approach that emphasizes understanding, meaning-making, and the ability to apply knowledge in new contexts (Fullan, Quinn, & McEachen, 2018). Unlike surface learning, which focuses on memorization and reproduction, deep learning encourages students to engage critically with content and construct their own understanding.

The concept of deep learning has been widely discussed in educational research, particularly in relation to higher-order thinking skills. Scholars such as John Biggs argue that meaningful learning occurs when teaching strategies, learning activities, and assessment are aligned to promote deep engagement with content (Biggs & Tang, 2007). This alignment is essential in helping students move beyond rote learning toward conceptual understanding.

In teacher education, deep learning plays a crucial role in developing pedagogical competence. Prospective teachers need to understand not only what to teach but also why and how to teach it effectively. Deep learning approaches encourage reflection, analysis, and the integration of theory and practice (Alzahrani & Alnufaie, 2024). However, implementing deep learning requires carefully designed instructional materials that support active engagement and critical thinking.

2.4. Tamansiswa Educational Philosophy in Contemporary Learning

Local educational philosophies offer valuable perspectives for contextualizing teaching and learning practices. The Tamansiswa philosophy, introduced by Dewantara (2013), emphasizes the principles of independence, cultural rootedness, and holistic development (Dewantara, 2013). Central to this philosophy is the idea that education should nurture not only intellectual growth but also moral and social values. In the context of modern education, integrating local philosophies such as Tamansiswa can enrich pedagogical practices by providing culturally relevant frameworks for teaching. This is particularly important in Indonesia, where educational practices are expected to reflect national identity and local wisdom (TEMPO.CO, 2020).

However, previous studies have shown that local educational philosophies are often discussed at a conceptual level without being systematically integrated into instructional materials (Sufian, 2023). As a result, their practical application in classroom settings remains limited. This gap suggests the need for instructional designs that explicitly incorporate Tamansiswa principles into teaching materials, thereby bridging the gap between theory and practice.

2.5. Synthesis of Previous Studies and Research Gap

A review of previous studies indicates that significant attention has been given to pedagogical competence, digital learning, and deep learning approaches (Imamyartha, Widiati, Anugerahwati, & Hamat, 2023; Yusupova et al., 2025; Zaqiah et al., 2024). However, these elements are often examined in isolation. Studies on digital teaching materials tend to focus on technological features without addressing pedagogical depth. Similarly, research on deep learning emphasizes cognitive processes but does not always consider cultural or contextual dimensions.

In addition, while the importance of local educational philosophies has been acknowledged (Rosa, Olivia, Gayatri, Fitria, & Rojabi, 2021; Sufian, 2023), there is limited research on how these philosophies can be operationalized within structured digital teaching materials. Consequently, prospective teachers often rely on fragmented resources that do not provide integrated guidance for developing pedagogical competence.

This study addresses these gaps by developing digital teaching materials that combine deep learning principles with Tamansiswa educational values. By integrating these elements within a structured framework, the study aims to provide a more holistic approach to teacher education that supports both conceptual understanding and cultural relevance.

3. METHODOLOGY

3.1. Research Design

This study employed a developmental research design using the ADDIE model, which consists of five interconnected phases: Analysis, Design, Development, Implementation, and Evaluation (Dick & Carey, 1996). This model was selected as it provides a systematic framework for developing and evaluating educational products, particularly digital teaching materials intended to support pedagogical competence.

In the analysis phase, preliminary data were collected to identify the needs and challenges faced by prospective and practicing elementary school teachers in developing pedagogical competence. The findings from this phase informed the design and structure of the instructional materials. The design phase focused on organizing the content based on deep-learning principles and integrating Tamansiswa educational values into the learning framework. During the development phase, the digital teaching materials were produced and subjected to expert validation to ensure their content validity and pedagogical relevance. The implementation phase involved applying the materials in real classroom settings, while the evaluation phase examined their effectiveness in improving pedagogical competence.

3.2. Participants and Research Context

The study was conducted within the context of teacher education at Sarjanawiyata Tamansiswa University in Yogyakarta, Indonesia. Participants were involved in two stages of field testing, namely a limited trial and a more extensive implementation.

The limited trial involved undergraduate students enrolled in the Elementary School Teacher Education Program. These participants represented prospective teachers who were still in the process of developing their foundational pedagogical competence. Their involvement in the initial phase allowed the researchers to examine the clarity, usability, and initial effectiveness of the developed digital teaching materials.

The extensive trial was conducted with postgraduate students in the Elementary Education Master's Program at the same institution. Most of these participants were practicing elementary school teachers who were simultaneously pursuing graduate studies. Their professional experience provided a more authentic context for evaluating the applicability of the materials in real classroom settings. This stage aimed to assess how the developed materials supported pedagogical competence in more complex, practice-oriented teaching situations.

Participants were selected purposively based on their relevance to the research objectives, particularly their involvement in elementary science learning and their need for structured instructional resources. This selection ensured that the data obtained reflected both pre-service and in-service teacher perspectives, thereby strengthening the overall validity of the study (Taherdoost, 2016).

3.3. Data Collection Techniques

To obtain comprehensive and reliable data, this study employed multiple data collection techniques, including observation, interviews, questionnaires, and pedagogical competence tests. The interview involved some points, such as 1) the condition of pedagogical competence possessed by teachers, 2) Availability of learning resources, 3) Utilization of digital technology in learning, 4) Integration of deep learning in learning, and 5) Integration of Tamansiswa teachings in learning.

Classroom observations were conducted to examine how participants engaged with the digital teaching materials and implemented instructional strategies. Interviews were carried out to explore participants' experiences, perceptions, and challenges during the learning process. In addition, a questionnaire was administered to gather participants' responses regarding the usability, clarity, and effectiveness of the developed materials (Khoiri, 2018; Mulyatiningsih, 2015; Sudaryono, 2016).

To assess pedagogical competence, a test was designed based on key indicators such as lesson planning, instructional strategy selection, classroom management, and assessment design. The instruments were developed in alignment with the research objectives and validated by experts before their use. Detailed specifications of the instruments, including indicators and item distributions, are provided in the appendix (see Appendix A).

3.4. Instruments

All research instruments underwent a validation process to ensure their validity and reliability (Sürücü & Maslakci, 2020). Expert judgment was employed to evaluate the relevance, clarity, and alignment of each instrument with the research objectives, with details of indicators as shown in Appendices B and C. Revisions were made based on expert feedback to improve the quality of the instruments before they were used in the field.

3.5. Data Analysis

Data analysis was conducted using both qualitative and quantitative approaches. Qualitative data obtained from observations and interviews were analyzed through thematic analysis, focusing on identifying patterns related to participants' learning experiences and pedagogical development.

Quantitative data from questionnaires and pedagogical competence tests were analyzed using descriptive statistics to measure changes in participants' competence and responses toward the developed materials. The scores were categorized based on their score ranges (see Table 1). The combination of these approaches allowed for a more comprehensive understanding of the effectiveness of the digital teaching materials in supporting pedagogical competence.

Table 1. Categorization of pedagogical competencies.

Value range	Category
81-100	Very good
61-80	Good
41-60	Fairly good
21-40	Less good
0-20	Not good

Furthermore, upon the product application in a limited and extensive trial, it was also tested for practicality by practitioners, lecturers, and students, with details presented in Appendices D and E. Appendix D presents the practicality test grid consisting of key indicators used to evaluate the feasibility and usability of the developed digital teaching materials. Appendix E presents the response grid used to capture lecturers' and students' perceptions of the materials, particularly in relation to their learning experience and ease of use.

3.6. Ethical Considerations

This study ensured that all participants were informed about the purpose of the research and their voluntary involvement. Consent was obtained before data collection, and participants' identities were kept confidential. The study adhered to ethical standards in educational research to maintain the integrity and credibility of the findings.

4. RESULTS

The results of this study indicate that, based on the needs analysis conducted through observation and interviews, the pedagogical competency of prospective teachers and current teachers remains low. This is evidenced by the following average pedagogical competency pre-test results that are presented in Table 2.

Table 2. Pretest results of pedagogical competency based on needs analysis for prospective teachers and teachers of elementary school.

No.	Category	Pretest result	Criteria
1	Prospective teacher (Bachelor's degree in elementary school teacher education)	43.27	Fairly good
2	Teacher (Master's degree in elementary education)	44.88	Fairly good

Observations also showed that the competencies of teachers and prospective teachers were still low. This was evident when asked about the differences between approaches, models, strategies, and methods; they still struggled to differentiate between the concepts. During discussions, they also struggled to ask questions, requiring assistance via ChatGPT. Those responsible for presentations also struggled to grasp the concepts, requiring assistance via ChatGPT.

Based on the needs analysis data, it is necessary to develop digital teaching materials to be able to become a variety of learning resources for teachers and prospective teachers, thereby helping them master concepts related to the nature of science, characteristics of science learning, approaches, models, strategies, media, methods, and appropriate assessments in science learning in elementary school. The developed teaching materials also need to be adapted to the Ministry's policy that has been launched, namely the principle of deep learning with characteristics of joyful, meaningful, and mindful learning.

The implementation of joyful learning principle in textbooks is implemented through activities such as ice breaking guessing myths or facts, inserting material in the form of interactive videos so that learning becomes fun, not tense and not boring, science adventure games in nature, making claps or cheers related to science, conducting experiments and adventures in science classes, practicing window shopping or role-playing learning methods, making tiktok edu-challenge: making videos of science teaching practices, making song or dance compositions related to science material, and playing scientific games using technology such as making quizzes through Kahoot, quizizz, and other applications.

The principle of meaningful learning in textbooks is implemented through reflective activities on the learning process, working on case studies related to the material, and so on. Furthermore, the implementation of the principle of mindful learning is implemented by ensuring that this learning process is carried out with full awareness by ensuring that participants understand the material being studied, such as being invited to make a summary of the material. Integration of Tamansiswa teachings carries out innovation with *Tri N* teachings, carries out reflection and real action through *Tri Nga*, and accompanies the learning process through the *Among* system.

The developed products were then tested for validity by material experts, language experts, and teaching materials experts. Results of material expert validation can be seen in Table 3.

Table 3. Product validation results by material experts.

No.	Aspect	Overall average
1	Material	4.875
2	Integration of deep learning	4.665
3	Integration of tamansiswa teaching	4.5
Percentage		93.55
Criteria		Very valid

Some of the notes provided by the material expert validator include: the developed teaching materials need to be strengthened with references to library sources from the main book, need to be supplemented with video content, images, and research results, and need to be supplemented with elementary school science learning outcomes. Furthermore, the validation results by the language and teaching materials experts can be seen in Table 4.

Table 4. Product validation results by language and teaching materials experts.

No.	Aspect	Average score
1	Self-instruction	3.5
2	Self-contained	3
3	Stand-alone	4
4	Adaptive	4
5	User friendly	3.57
Percentage		73 %
Criteria		Feasible / Valid

Some inputs provided by language and teaching materials experts include that teaching materials need to be equipped with concept maps for each chapter, illustrations such as charts, graphs, or photos, and ice-breaking activities should be linked to the teaching materials, according to each chapter. The integration of Tamansiswa teachings needs to be strengthened in learning activities, and deep learning integration is added with reflection activities with lecturers and students. Use reference sources from the last 10 years and complete the glossary and author profile with a description of the author's previous work. Based on the data above, it can be concluded that the overall average validation test from material experts, language experts, and teaching materials experts is 73 %, with a very feasible category. The product was also tested for practicality by three practitioners. The results of the practicality test can be seen in Table 5.

Table 5. Results of product practicality test by practitioners.

No.	Aspect	Overall average
1	Material	4.75
2	Principles of deep learning	4.23
3	Principles of tamansiswa teaching	4.67
4	Self instruction	4.67
5	Self contained	4.33
6	Stand alone	4.55
7	Adaptive	4.47
8	User friendly	4.72
9	Practicality	5
Percentage		91.97%
Criteria		Very practical

The expert input was then revised, and the revised product was pilot-tested to assess its effectiveness on the pedagogical competencies of teachers and prospective teachers. Detailed results of limited and extensive trials can be seen in the following sections.

4.1. Limited Trial Result

A limited trial was conducted on 33 prospective teachers currently studying elementary school teacher education. The trial design used a one-group pretest-posttest design. The limited trial included students completing pretest and posttest pedagogical competency questions, while observers observed the implementation of the learning process.

4.1.1. Descriptive Analysis Results

Upon the implementation of the limited trial to the teachers, the collected data were statistically analyzed using SPSS software. The results are presented in Table 6.

Table 6. Descriptive analysis results of the limited trial.

Variables			Statistic	Std. Error
Pretest Scores	Mean		43.27	1.557
	95% confidence interval for mean	Lower bound	40.10	
		Upper bound	46.44	
	5% trimmed mean		43.35	
	Median		40.00	
	Variance		80.017	
	Std. Deviation		8.945	
	Minimum		22	
	Maximum		60	
	Range		38	
	Interquartile range		12	
	Skewness		0.118	0.409
	Kurtosis		0.093	0.798
Posttest Scores	Mean		81.30	1.080
	95% confidence interval for the mean	Lower bound	79.10	
		Upper bound	83.50	
	5% trimmed mean		81.47	
	Median		80.00	
	Variance		38.468	
	Std. Deviation		6.202	
	Minimum		68	
	Maximum		92	
	Range		24	
	Interquartile range		10	
	Skewness		-0.102	0.409
	Kurtosis		-0.266	0.798

The results of descriptive analysis in Table 6 show that the pretest score had an average of 43.27 with a standard deviation of 8.95 and a median of 40.00, which indicates that the participants' initial abilities were relatively low with a fairly wide variation in achievement in the range of scores from 22 to 60. The distribution of pretest data tended to be normal with Skewness = 0.118 and Kurtosis = 0.093.

After treatment, the posttest score showed an average increase to 81.30 with a standard deviation of 6.20 and a median of 80.00, indicating that participants' achievement was generally higher and more balanced than before the treatment. The score range narrowed to 68 to 92, reducing the variation in achievement between participants. The posttest distribution was also normal with Skewness = -0.102 and Kurtosis = -0.266. Thus, the overall descriptive analysis results showed a significant increase from pretest to posttest, marked by an almost twofold increase in the average score, a decrease in the spread of values, and a distribution that remained normal. This indicates that the learning treatment provided was not only effective in improving participants' pedagogical competence but also able to equalize the quality of achievement between individuals.

4.1.2. Normality Test

As a prerequisite to conducting a correlational analysis, the test of normality for the collected data was conducted. The results are shown in Table 7.

Table 7. Normality test results in a limited trial.

Variables	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest score	0.188	33	0.004	0.946	33	0.098
Posttest score	0.159	33	0.034	0.943	33	0.083

Lilliefors significance correction

Note: The Kolmogorov-Smirnov test results are reported with Lilliefors significance correction (a), indicating that the normality assumption is tested based on sample-estimated parameters.

Results of the normality test with Kolmogorov-Smirnov and Shapiro-Wilk showed differences in significance values, and this is normal because both tests have different sensitivities. Kolmogorov-Smirnov tends to be more sensitive to small to medium sample sizes, while Shapiro-Wilk is more recommended for samples $n \leq 50$, according to the conditions of this study's data ($n = 33$). Based on the results of the Shapiro-Wilk test, the pretest score has a significance of $p = 0.098 > 0.05$, so it can be said to be normally distributed, and the posttest score has a significance of $p = 0.083 > 0.05$, which also indicates a normal distribution. Thus, both variables, both pretest and posttest, meet the assumption of normality.

4.1.3. Correlation Test

In order to know the relationship between the participants' initial abilities and their abilities after the use of the developed teaching materials, a correlational analysis was done. The results are presented in Table 8.

Table 8. Correlation test result in a limited trial.

Paired variables		N	Correlation	Sig.
Pair 1	Pretest score & Posttest score	33	0.717	0.000

The correlation analysis between pretest and posttest scores showed a correlation coefficient of 0.717, which is considered strong because it is close to +1. This indicates a strong positive relationship between pretest and posttest scores. In other words, participants with higher initial abilities tend to achieve higher results on the posttest. The positive correlation indicates that an increase in pretest scores is associated with an increase in posttest scores. Furthermore, the significance value obtained is $p = 0.000 (< 0.05)$, indicating that the relationship is statistically significant and does not occur by chance.

4.2. Extensive Trial

This extensive trial aims to measure the effectiveness of Digital Teaching Material Innovation Based on Deep Learning and Integrated Tamansiswa Teachings on a wider scale. The extensive trial in this study was conducted in all UST Elementary Education master's classes with a total of 103 participants. The effectiveness trial used a pretest-posttest control group design. The implementation of the Hyperbolin learning model was also assessed in the extensive trial. The effectiveness of the Hyperbolin model was analyzed using a t-test. The effectiveness of the data analysis is explained as follows.

4.2.1. Descriptive Analysis Results

After the implementation of the extensive trial on the participants, the collected data were statistically analysed using SPSS software. The results are presented in Table 9.

Table 9. Descriptive analysis results of the extensive trial.

Variables			Statistic	Std. Error
Pretest	Mean		44.620	1.418
	95% confidence interval for the mean	Lower bound	41.807	
		Upper bound	47.433	
	5% trimmed mean		44.522	
	Median		44.000	
	Variance		200.945	
	Std. Deviation		14.176	
	Minimum		20.00	
	Maximum		72.00	
	Range		52.00	
	Interquartile range		20.75	
	Skewness		0.110	0.241
	Kurtosis		-0.843	0.478
Posttest	Mean		84.900	0.697
	95% confidence interval for the mean	Lower bound	83.517	
		Upper bound	86.283	
	5% trimmed mean		84.867	
	Median		85.0000	
	Variance		48.596	
	Std. Deviation		6.971	
	Minimum		70.00	
	Maximum		100.00	
	Range		30.00	
	Interquartile range		11.00	
	Skewness		0.030	0.241
	Kurtosis		-0.665	0.478

Based on Table 9, the descriptive statistical analysis of pedagogical competence scores provides information on the distribution of the pretest and posttest data. The pretest score had a mean of 44.62 with a standard deviation of 14.18. The median was 44.00, with scores ranging from 20.00 to 72.00, resulting in a range of 52.00 and an interquartile range of 20.75. The skewness (0.110) and kurtosis (-0.843) values were both close to zero, indicating that the pretest scores were approximately normally distributed.

The posttest score showed a mean of 84.90 with a standard deviation of 6.97. The median was 85.00, while the minimum and maximum scores were 70.00 and 100.00, respectively, resulting in a range of 30.00 and an interquartile range of 11.00. The skewness (0.030) and kurtosis (-0.665) values also indicated an approximately normal distribution. Compared with the pretest results, the posttest scores showed a substantial increase in the average score (from 44.62 to 84.90), accompanied by a smaller standard deviation, suggesting improved pedagogical competence and more consistent performance among participants following the implementation of the developed digital teaching materials.

4.2.2. Normality Test Result

As a prerequisite to conducting a correlational analysis, the test of normality for the collected data in an extensive trial was conducted. The results are shown in Table 10.

Table 10. Normality test results in an extensive trial.

Variables	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
Pretest	0.098	100	0.020	0.965	100	0.010
Posttest	0.109	100	0.005	0.978	100	0.098

Lilliefors significance correction

Note: The Kolmogorov-Smirnov test results are reported with Lilliefors significance correction (a), indicating that the normality assumption is tested based on sample-estimated parameters.

A normality test was conducted to examine whether the pretest and posttest pedagogical competence scores were normally distributed before applying parametric statistical analyses. As shown in Table 10, the Kolmogorov–Smirnov test yielded significance values of 0.020 for the pretest and 0.005 for the posttest, both of which are below 0.05, indicating departures from normality according to this test. However, because the sample size was 100, the Kolmogorov–Smirnov test is known to be highly sensitive to minor deviations from normality. Therefore, greater emphasis was placed on the Shapiro–Wilk test and the overall distributional characteristics. The Shapiro–Wilk test showed a significance value of 0.010 for the pretest and 0.098 for the posttest. Although the pretest slightly deviated from normality according to the Shapiro–Wilk test, the skewness and kurtosis values presented in Table 9 were within acceptable ranges, indicating that the data were approximately normally distributed. Moreover, the paired-samples t-test is considered robust to moderate violations of the normality assumption, particularly with relatively large samples. Therefore, the data were considered suitable for subsequent parametric analysis using the paired-samples t-test.

4.2.3. Correlation Test Result

In order to know the relationship between the participants' initial abilities and their post-abilities after the use of the developed teaching materials in the extensive trial phase, a correlational analysis was done. The results are presented in Table 11.

Table 11. Correlation test results in the extensive trial phase.

Pair		N	Correlation	Sig.
Pair 1	Pretest & Posttest	100	-0.120	0.235

A paired-sample correlation analysis was conducted to examine the relationship between participants' pretest and posttest pedagogical competence scores. As presented in Table 11, the correlation coefficient was -0.120, indicating a very weak negative relationship between the two sets of scores. However, this correlation was not statistically significant ($p = 0.235$, $p > 0.05$). Therefore, there was no significant linear relationship between participants' pretest and posttest scores. This finding suggests that participants' initial pedagogical competence was not significantly associated with their posttest performance after using the developed digital teaching materials.

4.2.4. Results of the T-Test Effectiveness Test

The paired T-test was done to determine the difference in scores between the pretest and posttest. The result of the analysis is shown in Table 12.

Table 12. T-Test result.

Paired Samples		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest- Posttest	-40.280	16.530	1.653	-43.560	-37.000	-24.368	99	0.000

The Paired Samples t-test was conducted to determine the difference in pedagogical competence between pretest and posttest scores. Based on the SPSS output shown in Table 12, the mean difference value was -40.28, with a standard deviation of 16.52 and a standard error of 1.65. T-test results showed a t value = -24.368 with degrees of freedom (df) = 99 and a significance (Sig. 2-tailed) of 0.000 (< 0.05). Thus, it can be concluded that there is a very significant difference between pretest and posttest scores of students' problem-solving abilities. The posttest mean

value (84.90) is higher than the pretest mean value (44.62), so the learning treatment provided is proven to be effective in improving teachers' and prospective teachers' Pedagogical Competence.

4.2.5. SEM Analysis Results

As mentioned previously, the pedagogical competence of the participants in the present study might be influenced by some factors, including the deep learning integration, digital teaching material innovation, and the integration of Tamansiswa noble values (Tamansiswa teaching integration). Hence, to know their factorial effects, the SEM analysis was done. The results are presented in Figure 1.

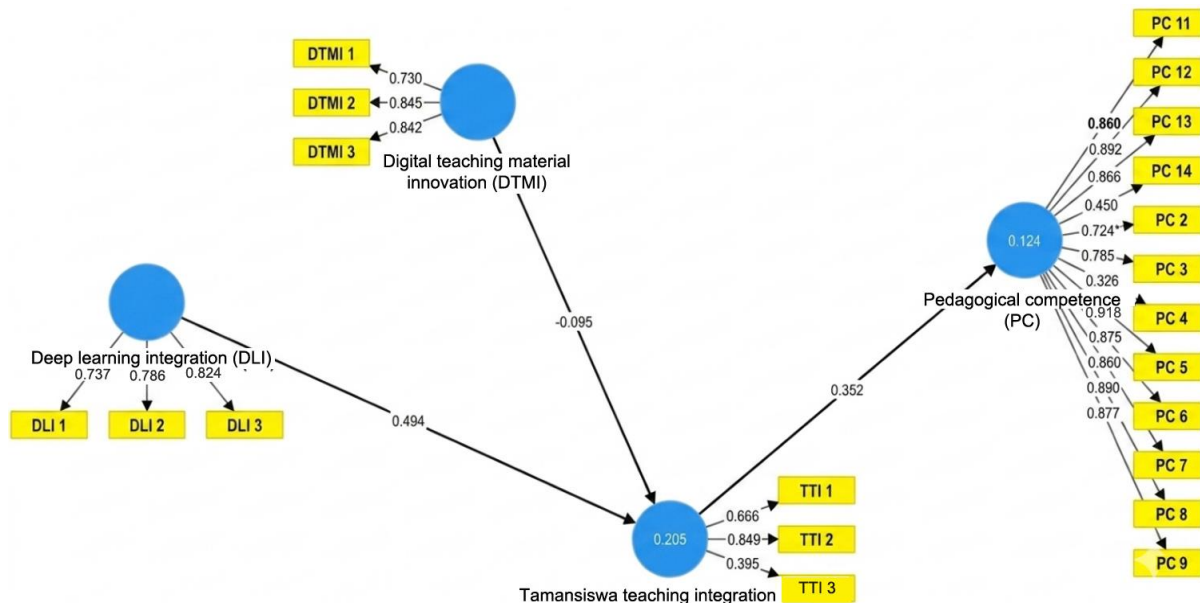


Figure 1. SEM analysis graphic output.

Based on the results of Structural Equation Modeling (SEM) analysis (see Figure 1), this research model examines the relationships among four latent constructs: Digital Teaching Material Innovation (DTMI), Tamansiswa Teaching Integration (TTI), Deep Learning Integration (DLI), and Pedagogical Competence (PC). The results indicate that the proposed model provides information about the measurement properties of the constructs and the relationships among the variables within the research framework.

The construct validity and reliability were examined based on the indicator loading values. The DLI construct is reflected by three indicators, with loading values of 0.737, 0.786, and 0.824, respectively. These values indicate that the three indicators represent Deep Learning Integration, with the largest contribution coming from DLI3. The DTMI construct also shows strong indicator loadings, with values of 0.730 for DTMI1, 0.845 for DTMI2, and 0.842 for DTMI3. These values indicate that the three indicators represent Digital Teaching Material Innovation. For the TTI construct, the loading values vary across the three indicators: 0.666 for TTI1, 0.849 for TTI2, and 0.395 for TTI3. TTI1 and TTI2 show stronger contributions, whereas TTI3 has a comparatively low loading value and warrants further examination. The PC construct is represented by indicators with varying loading values. Relatively high values are observed for PC4 (0.916), PC5 (0.875), PC6 (0.860), and PC13 (0.892), whereas lower values are observed for PC2 (0.450) and PC3 (0.326). These lower-loading indicators should be examined further when evaluating the measurement quality of the Pedagogical Competence construct.

The structural model indicates a positive path coefficient from Deep Learning Integration (DLI) to Tamansiswa Teaching Integration (TTI) ($\beta = 0.494$), whereas the path from Digital Teaching Material Innovation (DTMI) to TTI is negative ($\beta = -0.095$). TTI, in turn, has a positive path coefficient to Pedagogical Competence (PC) ($\beta = 0.352$). These coefficients describe the direction and magnitude of the estimated relationships among the constructs.

However, the statistical significance of these relationships cannot be established from the path coefficients alone and should be verified using the corresponding significance tests or bootstrap confidence intervals. The values displayed inside the TTI and PC constructs should be interpreted separately according to the original SEM output.

Table 13. SEM regression test.

Endogenous variables	R-square	R-square adjusted
Tamansiswa Teaching Integration	0.205	0.188
Pedagogical competence	0.124	0.115

Table 13 shows that the model explains 20.5% of the variance in Tamansiswa Teaching Integration (TTI), with an adjusted R-square of 0.188. For Pedagogical Competence (PC), the R-square value is 0.124, while the adjusted R-square is 0.115. These results indicate that the model accounts for a relatively small proportion of the variance in pedagogical competence. Other factors not included in the model may also contribute to differences in pedagogical competence among participants. Therefore, the explanatory capacity of the model should be interpreted cautiously, and further research may consider additional theoretically relevant predictors. The R-square values alone do not establish the statistical significance of individual structural paths or demonstrate predictive performance beyond the observed sample. The developed product was also asked for responses from prospective teachers in a limited trial, with the following results.

Table 14. Prospective teachers' responses to the product in a limited trial.

No.	Aspect	Overall average
1	Material	5
2	Principles of deep learning	4.25
3	Principles of tamansiswa teachings	4.25
4	Self instruction	4.25
5	Self contained	4.125
6	Stand alone	4.25
7	Adaptive	4.45
8	User friendly	4.42
9	Ease of use	4.5

Table 14 presents prospective teachers' responses to the product in a limited trial. The results show that the material aspect received the highest average score of 5, followed by ease of use (4.5), adaptive aspect (4.45), and user-friendly aspect (4.42). Other aspects, including principles of deep learning, principles of Tamansiswa teachings, self-instruction, and stand-alone, each obtained a score of 4.25, while self-contained scored 4.125. These findings indicate that the product is perceived as highly practical and well accepted by prospective teachers.

Finally, the results of respondents' responses to the extensive trial are shown in Table 15.

Table 15. Teacher responses to the product in an extensive trial.

No.	Aspect	Overall average
1	Material	4.79
2	Principles of deep learning	4.66
3	Principles of tamansiswa teachings	4.83
4	Self instruction	4.25
5	Self contained	4.5
6	Stand alone	4.56
7	Adaptive	4.76
8	User friendly	4.47
9	Ease of use	4.83

Table 15 presents teachers' responses to the product in an extensive trial. The results show that the principles of Tamansiswa teachings and ease of use obtained the highest average score of 4.83, followed by adaptive aspect (4.76), material (4.79), and principles of deep learning (4.66). Other aspects, including stand-alone (4.56), self-contained (4.5), and user-friendly (4.47), also show high ratings, while self-instruction received the lowest score of 4.25. These findings indicate that the product is highly practical and well accepted by teachers in broader implementation.

5. DISCUSSION

The findings of this study confirm that the developed digital teaching materials are valid, practical, and effective in improving the pedagogical competence of prospective elementary school teachers. The substantial increase in scores from pretest to posttest indicates that the intervention supported meaningful learning rather than surface-level understanding. This result reflects the nature of pedagogical competence as a complex construct involving the ability to design, implement, and evaluate learning in a reflective manner (Haryanto, Weda, & Nashruddin, 2018). It also supports earlier findings by Wardoyo et al. (2020), who emphasize that well-structured instructional design contributes significantly to strengthening teachers' competencies. However, the present study extends this perspective by integrating cognitive engagement and cultural values into a digital learning environment.

The effectiveness of the materials can be explained through the application of deep learning principles. The learning process encouraged students to engage in analysis, reflection, and knowledge construction, which are central characteristics of deep learning (Suyanto, 2025). Unlike traditional approaches that focus on memorization, the activities in this study required students to connect concepts with practice and solve contextual problems. This aligns with Almulla (2023), who found that problem-solving and creative thinking tasks significantly improve learning performance. Therefore, the improvement in pedagogical competence can be interpreted as the result of sustained cognitive engagement that enables learners to internalize pedagogical concepts more deeply.

In addition to cognitive aspects, the integration of Tamansiswa values provides a strong cultural foundation for learning. The Tri N principles of observing, imitating, and extending (in Javanese: *niteni, nirokke, nambahi*) offer a structured pathway for knowledge construction that is both gradual and meaningful. Dewantara (2013) emphasizes that education should promote independence and contextual awareness, which are reflected in these principles. Previous research by Nisa, Prasetyo, and Istiningsih (2019) also shows that the application of Tri N enhances students' creativity and engagement. This study builds on that finding by demonstrating that such values are not only relevant for school students but also effective in shaping the pedagogical competence of future teachers. The integration of cultural philosophy within digital materials creates a learning experience that is both relevant and transformative.

The high level of practicality further indicates that the developed materials are feasible for implementation in real classroom settings. According to Mulyatiningsih (2015), practical learning products are those that can be used effectively without requiring major adjustments. The positive responses from users suggest that the materials successfully bridge theoretical design and practical application. This finding is consistent with Wijayanti et al. (2025), who highlight that well-designed digital resources play an important role in enhancing teaching and learning processes, particularly in supporting digital literacy.

More importantly, this study addresses a significant research gap identified in previous literature. Earlier studies tend to examine digital learning, deep learning, and cultural values separately. For instance, Anwar et al. (2025) focus on technological readiness through a technological pedagogical framework but do not incorporate cultural dimensions. On the other hand, studies on Tamansiswa emphasize philosophical values without integrating digital pedagogy. By combining these elements, this study offers a more comprehensive framework that connects cognitive processes, cultural context, and technological innovation. This integration provides a meaningful contribution to teacher education, particularly in contexts where local values remain an essential part of learning.

6. CONCLUSION

This study set out to address the limited availability of structured digital resources capable of supporting teachers in designing meaningful elementary science instruction. The findings demonstrate that the developed digital teaching materials, constructed through the ADDIE framework and informed by a deep-learning orientation and Tamansiswa educational principles, provide a feasible and practical tool for strengthening pedagogical competence. The materials not only supported teachers in selecting appropriate strategies, media, and assessments but also encouraged reflective and creative lesson design through activities emphasizing observation, imitation, and innovation. The significant improvement in pedagogical competence scores across both limited and broader trials indicates that thoughtfully designed digital materials can function as an effective bridge between technological use and sound pedagogical practice, particularly in science learning contexts that require conceptual understanding and active engagement.

Several limitations should be acknowledged. The measurement of pedagogical competence relied primarily on test-based indicators of instructional planning, and classroom enactment was not examined in depth. In addition, the study was conducted within a specific institutional and cultural setting, which may limit broader generalization. Future research could incorporate classroom observations, longitudinal designs, or comparative interventions to better capture how teachers translate these materials into sustained instructional change across diverse contexts.

Practically, the study suggests that digital resource development should move beyond technical delivery to embed pedagogical reflection and local educational values, enabling teacher professional growth alongside digital innovation.

Funding: This research was funded by the Ministry of Higher Education, Science, and Technology, Directorate General of Research and Development, Indonesia, under contract numbers No. 126/C3/DT.05.00/PL/2025; No. 0498.02/LL5-INT/AL.04/2025; and No. 006/DPPM.LLDIKTI/PFR/UST/LP2M/K/VI/2025.

Institutional Review Board Statement: This study received ethical approval from the Directorate of Postgraduate Education, Sarjanawiyata Tamansiswa University, Indonesia. The approval was granted on July 7, 2025, under protocol number No. 178/UST/DPsP-DIR/VII/2025.

Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

Competing Interests: The authors declare that they have no competing interests.

Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Disclosure of AI Use: The author(s) used OpenAI's ChatGPT to edit and refine the wording of the Introduction. All outputs were reviewed and verified by the authors.

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Appendices

Appendix A. Pedagogical competency test grid.

No.	Indicators	Instrument item
1	Ability to understand student characteristics and consider them when designing learning tools	1
2	Ability to understand the material contained in the learning objectives	1
3	Ability to understand the learning environment and consider it when designing learning tools	1
4	Ability to determine learning approaches according to learning objectives	1
5	Ability to determine the appropriate learning model according to learning objectives	1

No.	Indicators	Instrument item
6	Ability to determine appropriate methods and strategies according to learning objectives	1
7	Ability to determine the appropriate media to achieve learning objectives	1
8	Ability to utilize technology according to learning objectives	1
9	Ability to create fun and interesting learning experiences according to student characteristics	1
10	Ability to develop students' potential in the learning process	1
11	Ability to carry out assessment and evaluation of learning according to learning objectives	1
12	Ability to reflect on the learning that has been done	1

Appendix B. Validation test sheet grid from material experts.

No.	Indicators
1	Material
2	Integration of deep learning
3	Integration of tamansiswa teachings

Appendix C. Grid of validation test sheet from language and teaching materials experts.

No.	Indicators
1	Self-Instruction
2	Self-Contained
3	Stand alone
4	Adaptive
5	User friendly

Appendix D. Practicality test grid.

No.	Indicators
1	Material
2	Principles of deep learning
3	Principles of tamansiswa teachings
4	Self-Instruction
5	Self-Contained
6	Stand alone
7	Adaptive
8	User friendly
9	Practicality

Appendix E. Grid of responses from lecturers and students (Teachers and prospective teachers).

No.	Indicators
1	Material
2	Principles of deep learning
3	Principles of tamansiswa teachings
4	Self-Instruction
5	Self-Contained
6	Stand alone
7	Adaptive
8	User friendly
9	Ease of use

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