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Implementation of SSP (Subject-Specific Pedagogy) Based on TPACK for Students' Scientific Literacy Skills

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ABSTRACT

This study aims to examine the effect of implementing Subject-Specific Pedagogy (SSP) based on the Technological Pedagogical Content Knowledge (TPACK) framework on students' scientific literacy skills in science learning. The study employed a quantitative experimental design with a one-group pre-test–post-test. The participants were students from the Elementary Teacher Education Program at Universitas Muria Kudus, selected using a simple random sampling technique. Data were collected using a scientific literacy test covering scientific knowledge, scientific competence, and contextual understanding. The data were analyzed using descriptive statistics, normalized gain (N-gain), and a paired sample t-test. The results showed that students' scientific literacy skills increased significantly after the implementation of a TPACK-based SSP, as indicated by an improvement in the average score from the medium category in the pre-test to the very high category in the post-test, with an N-gain in the moderate category and a statistically significant difference between pre-test and post-test scores. These findings indicate that integrating pedagogy, content, and technology through TPACK-based SSP effectively enhances students' scientific literacy. This study contributes to science education by providing empirical evidence that a TPACK-based SSP can be an effective instructional approach to strengthen scientific literacy among pre-service elementary school teachers and to support the development of science learning aligned with the demands of the digital era.

ARTICLE INFORMATION

Keywords:
Scientific literacy; SSP; TPACK

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INTRODUCTION

Learning in higher education is expected to involve applying appropriate learning approaches to achieve optimal learning outcomes. However, university learning practices are still predominantly dominated by monotonous, conventional methods, particularly in science learning (Kurniasari & Mardikaningsih, 2022). Consequently, student learning outcomes remain unsatisfactory, as indicated by generally low achievement levels in science courses (Suryaneza & Permanasari, 2016). In the learning process, teachers should consistently place students at the center. When student-centered learning becomes the foundation of teachers' perspectives and instructional practices, the quality of learning is more likely to improve in response to the demands of digital and science-based education (Doloksaribu & Suaka, 2018). In instructional practice, teachers determine learning objectives, prepare learning tools, implement learning activities, and conduct assessments to evaluate students' learning outcomes. To ensure learning objectives are effectively achieved, teachers require appropriate, high-quality assessment instruments (Kurniasari & Mardikaningsih, 2022). One approach that integrates the preparation of learning tools is Subject-Specific Pedagogy (SSP), which

systematically combines syllabi, lesson plans, teaching materials, student worksheets, learning media, and learning assessments into a unified instructional framework (Hadi et al., 2020). Learning planning is a crucial component of instructional success because it represents a rational decision-making process grounded in clearly defined learning goals and objectives (Betari, 2016).

In addition, lecturers are required to adapt learning strategies to the characteristics of students who are familiar with and accustomed to using digital technology. The Technological Pedagogical Content Knowledge (TPACK) framework emphasizes the integration of technology, pedagogy, and content knowledge in learning (Fakhriyah et al., 2023; Fakhriyah et al., 2022). TPACK refers to lecturers' knowledge of how to facilitate student learning of specific content through appropriate pedagogical strategies and technological tools (Cox & Graham, 2009; Koehler et al., 2012; Koehler & Mishra, 2009; Octaviana & Setiawan, 2019; Rahmadi, 2019). The integration of TPACK into learning design is expected to enhance learning effectiveness and increase student engagement, particularly in science learning. One essential competency required to respond to the rapid development of science and technology is scientific literacy (Mayasari & Paidi, 2022). Nevertheless, scientific literacy levels in Indonesia remain relatively low, partly due to limited attention to socio-cultural contexts and local potential as learning resources. In fact, socio-cultural environments and local potential can serve as meaningful learning resources to strengthen students' understanding of scientific concepts (Hadi et al., 2020). Data from the Programme for International Student Assessment (PISA) indicate that Indonesia's scientific literacy score in 2015 was 403, ranking 62nd out of 70 participating countries (OECD, 2017).

Low scientific literacy levels are also associated with learning practices that remain teacher-centered and do not actively involve students in the learning process. As a result, students tend to become passive, and the utilization of learning resources and media does not optimally support learning success. Scientific literacy refers to students' ability to understand scientific phenomena in the context of relevant issues and to apply scientific knowledge to solve problems and make appropriate decisions (Sholikah et al., 2020). Therefore, scientific literacy skills need to be continuously developed through structured learning activities to optimize student learning outcomes. Scientific literacy plays a vital role in enabling students to understand issues related to the environment, health, economics, modern society, and technology. Rapid technological advancements influence individuals' behavior and habits, particularly in how they access and evaluate information. Consequently, the increasing availability of information in the digital era must be balanced with adequate knowledge, attitudes, and skills characteristic of the Industry 4.0 generation (Masfuah et al., 2022; Mayasari & Paidi, 2022; Sakti et al., 2021). In a comprehensive sense, scientific literacy encompasses four domains: context, scientific competence, scientific knowledge, and attitudes toward science (Janah et al., 2018; Sakti et al., 2021).

Scientific literacy skills must be systematically developed by teachers so that they become embedded in students' learning experiences. Through exposure to scientific facts and inquiry-oriented learning activities, students are expected to actively engage with their environment, solve problems, and make informed decisions. In the 21st century, scientific literacy is regarded as a key learning outcome because mastery of science and technology constitutes a fundamental indicator of national progress (Betari, 2016). Empirical evidence shows that students in the Elementary School Teacher Education Program predominantly demonstrate scientific literacy at nominal and functional levels, indicating limited ability to connect scientific concepts with real-world contexts (Fakhriyah et al., 2017). Although previous studies have examined SSP or TPACK independently, empirical research that integrates SSP within the TPACK framework and evaluates its direct impact on students' scientific literacy skills, particularly among pre-service elementary school teachers, remains limited. This study addresses this research gap by implementing TPACK-based Subject-Specific Pedagogy (SSP) as a

comprehensive instructional approach in science learning. The novelty of this study lies in its empirical examination of TPACK-based SSP not merely as a learning design or technological integration, but as a structured pedagogical system that directly enhances students' scientific literacy outcomes. Based on these considerations, this study aims to determine the effect of implementing TPACK-based SSP on students' scientific literacy skills in science learning.

METHOD

This study employed a quantitative research approach, using an experimental design with a one-group pre-test–post-test. This design was chosen to examine the effect of implementing Subject-Specific Pedagogy (SSP) grounded in the Technological Pedagogical Content Knowledge (TPACK) framework on students' scientific literacy skills, comparing learning outcomes before and after the intervention (Creswell & Clark, 2011; Fraenkel et al., 2012). The objective of this study was to determine whether the application of TPACK-based SSP could improve students' scientific literacy in science learning. The participants in this study were 41 students from the Elementary Teacher Education Program at Universitas Muria Kudus enrolled in science courses. The sampling technique used was simple random sampling, which was applied to provide equal opportunities for all members of the population to be selected and to minimize sampling bias (Sugiyono, 2015). The research procedure began with a pre-test to assess students' initial scientific literacy skills. Subsequently, students participated in science learning activities through the implementation of TPACK-based SSP. After the learning intervention, a post-test was administered to assess students' scientific literacy skills.

The learning intervention was conducted by applying TPACK-based SSP, which integrates learning objectives, instructional strategies, learning materials, digital learning media, and assessment into a unified instructional framework. This approach was designed to facilitate active learning and to support the development of scientific literacy by engaging students in understanding scientific concepts, applying scientific reasoning, and interpreting scientific phenomena in real-life contexts. The research instrument used in this study was a scientific literacy test comprising questions on science concepts and contextual scientific issues. The instrument was developed based on scientific literacy indicators, including scientific knowledge, scientific competence, and context (OECD, 2017; Narut & Supardi, 2019), and was reviewed by experts to ensure its content validity before use.

Data analysis was conducted using descriptive and inferential statistical techniques. Descriptive analysis was used to calculate the mean scores for students' scientific literacy on the pre-test and post-test. The improvement in students' scientific literacy skills was analyzed using the normalized gain (N-gain) approach to determine the effectiveness of the learning intervention (Hake, 1999). In addition, a paired-samples t-test was conducted to examine whether there was a significant difference in students' scientific literacy skills before and after the implementation of a TPACK-based SSP. Before conducting the t-test, a normality test was performed to ensure the data met the assumptions of parametric statistical analysis (Supriadi, 2021). The research stages are illustrated in Figure 1, which presents the research flowchart from initial preparation through data analysis and interpretation.

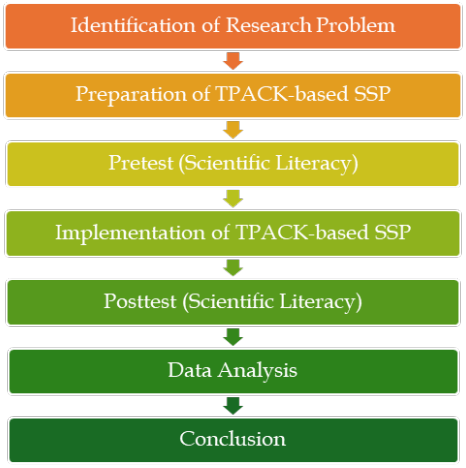

Figure 1. Research Flowchart

RESULTS AND DISCUSSION

The implementation of TPACK-based Subject-Specific Pedagogy (SSP) resulted in a significant improvement in students' scientific literacy skills. A paired-samples t-test indicated a significant difference in students' scientific literacy performance before and after the learning intervention, demonstrating the effectiveness of the instructional approach. Furthermore, the distribution of students' scientific literacy categories shifted substantially from medium and high levels in the pre-test to predominantly very high levels in the post-test, indicating meaningful learning progress across participants. Table 1 presents the differences between the pre-test and post-test using a paired-samples T-test.

Table 1. Differences In Pre-Test and Post-Test with Paired-Samples T-Test

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre-test – Post-test	-32.000	9.287	1.450	-34.931	-29.069	-22.063	40	.000

Research has been conducted by applying the TPACK-based SSP to learning science materials. Students are given scientific literacy tests in the form of a pre-test and a post-test. The scores obtained by students were used to calculate the initial and final results of students' scientific literacy skills using formula 1. A paired t-test was then performed, which indicated normality ($p \geq 0.05$), confirming that the data were normally distributed. For the results of the paired t-test (Table 1), the significance was 0.00 (<0.05), indicating that students' scientific literacy skills differed after using a TPACK-based SSP in learning science material. The analysis of learning gains further confirmed that the application of TPACK-based SSP led to moderate-to-high improvements in students' scientific literacy skills. The majority of students demonstrated measurable learning gains, indicating that the learning intervention supported not only conceptual understanding but also students' ability to apply scientific knowledge in contextual situations.

In previous research, Fakhriyah et al. (2022) found students' TPACK abilities to be in a good category. The TPACK profile was determined by the most contributing factors: 51% by those who entered PK and CK; the remaining 49% by other factors outside the TPACK model. These findings were then used to develop SSP in the form of learning tools and an LMS to encourage the growth of TPACK students in scientific literacy skills (Fakhriyah et al., 2022). Appropriate SSP development needs to be designed in a planned and comprehensive manner, covering aspects of knowledge, attitudes, and skills. In addition, SSP development pays attention to material characteristics, is based on 4C, and includes strengthening literacy. SSP can be interpreted as the packaging of subject matter into a comprehensive and educational learning set. In this study, the SSP that was developed included a syllabus, lesson plans, textbooks, worksheets, ICT-based learning media, and assessments that strengthen students' scientific literacy. TPACK is the ability of lecturers to organize learning by integrating learning strategies and learning technology. So this is what distinguishes the depth of competence mastery for each subject lecturer. With the TPACK approach to learning, lecturers can streamline pedagogical practices and deepen understanding of concepts by integrating technology. The TPACK approach aims to develop lecturers' creativity and skills in using technology in learning and to enhance students' learning experience. The TPACK learning model is an excellent solution for learning because it makes it easier for lecturers to integrate technology with pedagogical content and also encourages students to participate in learning, helping them understand the subject matter provided by the lecturer, which directly impacts student learning outcomes.

By mastering scientific literacy, students are expected to know, choose, and sort information tailored to their scope and field. In addition, students can examine information about contextual issues and apply it in everyday life to address personal and societal problems. Even so, learning science through scientific literacy is not easy; in the conceptual dimension of science, scientific literacy must relate understanding of key concepts to certain natural phenomena and to changes resulting from human activity. Scientific literacy is individual scientific knowledge and the ability to use that knowledge to identify problems, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions related to scientific issues. Then, students understand the main characteristics of knowledge that builds on human knowledge and inquiry, is sensitive to how science and technology shape the material, intellectual, and cultural environment, and is willing to engage with issues and ideas related to science (Irien, 2023). Students need these competencies so that the information they access can be scientifically studied and tested for truth, preventing hoaxes and incorrect information. In addition, scientific literacy learning continues to develop in line with scientific development and social interaction. The results showed that, in general, students who implemented the TPACK-based SSP had an average pre-test score of 53.07 in the medium category, while the post-test score was 85.05 in the very high category, as shown in Table 2.

Table 2. Pre-test and Post-test Analysis of Scientific Literacy Skills

Percentage (%)	Criteria for Students' Scientific literacy skills	Frequency	
		Pre-test	Post-test
0 ≤ x≤ 20	Very Low	0	0
20 < x ≤ 40	Low	1	0
40 < x ≤ 60	Medium	24	0
60 < x ≤ 80	High	16	2
80 < x ≤ 100	Very High	0	39
Average value		53,07	85,05

From the pre-test and post-test analysis of students' scientific literacy skills, there is a difference of 31.98, with a 37.6% increase from the initial value after the application of a TPACK-based SSP in science learning. In Table 2, it can be seen that there are differences between the students' post-test and pre-test results. Students' scientific literacy skills during the pre-test showed 16 students in the high category, 24 in the medium category, and 1 in the low category. As for the post-test, 2 students scored in the high category and 39 in the very high category. Scientific literacy skills show that students can use content, procedural, and epistemic knowledge to provide explanations, evaluate and design scientific questions, and interpret data in several life situations (Cox & Graham, 2009). After knowing that there are differences in scientific literacy skills, the N-gain score is calculated with the results shown in Table 3 and Figure 3 to find out and explain the increase in students' scientific literacy skills after using the application of TPACK-based SSP in science learning. The results of the N-gain calculation of students' post-test and pre-test scores showed an increase. Based on the results of the overall analysis of students' scientific literacy skills after being given the application of TPACK-based SSP in learning science material, with very high criteria, and an increase in N-gain in the medium category, with an average value of 0.68 or 68%. Figure 2 shows the number of students by category.

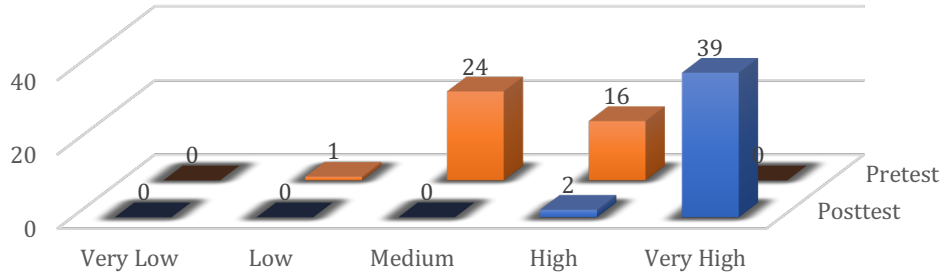

Figure 2. Number of Students by Category

A more complete explanation, based on Table 2 and Figure 3, shows that the high category comprises 17 students (41.46%) and the medium category comprises 24 students (58.54%). Increasing students' scientific literacy skills is achieved when applying TPACK-based SSP in science learning in the moderate category, which, when used, can help achieve learning objectives and make it easier for students to construct concepts and knowledge in line with their level of development. Appropriate SSP development needs to be designed in a planned and comprehensive manner, covering aspects of knowledge, attitudes, and skills. In addition, SSP development needs to pay attention to the material's characteristics, based on 4C, and include strengthening literacy. SSP can be interpreted as the packaging of subject matter into a comprehensive and educational learning set. In this study, the SSP developed included a syllabus, lesson plans, textbooks, worksheets, ICT-based learning media, and strengthened students' scientific literacy. Table 3 presents the percentages for the scientific literacy skills indicators.

Table 3. Percentage of Scientific Literacy Skills Indicators

N-Gain	Category	Frequency	Percentage (%)
-1,00 ≤ g < 0,00	Down	0	0
g = 0,00	Still	0	0
0,00 < g < 0,30	Low	0	0
0,30 ≤ g < 0,70	Medium	24	58,54
0,70 ≤ g ≤ 1,00	High	17	41,46
Average N-Gain			0,68 (68%)

Increasing students' scientific literacy is achieved through learning science material. Science education is expected to become the main foundation of education, serving as a vehicle for students to understand and apply it in everyday life. Improving the quality of science learning requires scientific literacy skills. Scientific literacy is knowledge and understanding of scientific concepts and processes that support personal decision-making, participation, and productivity. Scientific literacy comprises four elements: context, competence, knowledge, and attitudes (Sari & Koto, 2023). N-Gain for each category of scientific literacy skills is displayed in Figure 3.

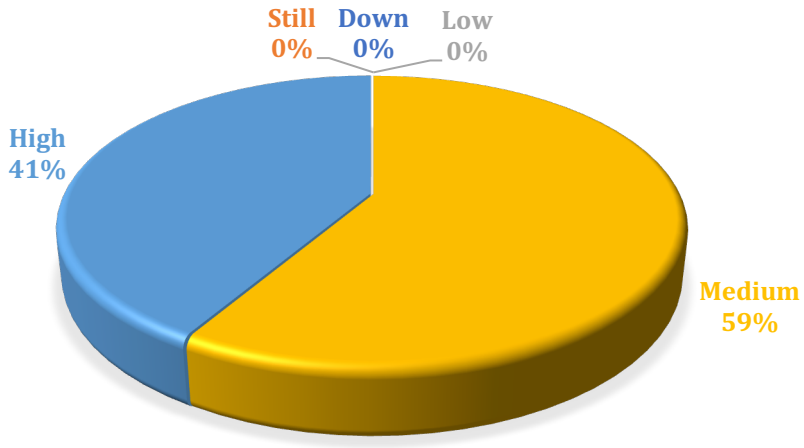

Figure 3. N-Gain for Each Category

The findings of this study demonstrate that applying TPACK-based Subject-Specific Pedagogy (SSP) effectively enhances students' scientific literacy, particularly through the integration of scientific knowledge, processes, and contextual understanding. Unlike conventional instructional approaches that often emphasize content transmission, TPACK-based SSP enables the systematic integration of pedagogy, content, and technology to design learning activities, allowing students to construct knowledge and apply scientific reasoning in real-world contexts actively. When compared to instructional approaches such as project-based learning or inquiry-based learning, which primarily focus on student activities or problem-solving structures (Budiarti & Tanta, 2021; Sholahuddin et al., 2023). TPACK-based SSP offers a more comprehensive pedagogical framework. The integration of TPACK within SSP ensures that learning objectives, instructional strategies, digital learning media, and assessment are coherently aligned. This alignment supports students not only in understanding scientific concepts but also in interpreting data, evaluating evidence, and connecting scientific ideas with technological applications and contextual issues.

The improvement in students' scientific literacy can be explained by the way TPACK-based SSP facilitates multidimensional learning experiences. Pedagogically, SSP structures learning activities that encourage inquiry and reflection; technologically, TPACK enables the use of digital media to visualize abstract scientific concepts; and conceptually, content knowledge is contextualized within real-life scientific phenomena. This combination creates meaningful learning experiences that foster deeper understanding and higher-order thinking skills, which are essential components of scientific literacy. Recent studies emphasize that scientific literacy enables individuals to evaluate scientific information critically, solve problems based on evidence, and make informed decisions related to environmental and technological issues (Fabian et al., 2019; Glowatz & O'Brien, 2017; Shofawati et al., 2023; Utami & Utami, 2023). From a scientific perspective, this study contributes empirical evidence to the growing body of research on science education by demonstrating that the effectiveness of

TPACK lies not only in technological integration but in its systematic application within a structured pedagogical framework such as SSP. In practice, the findings suggest that a TPACK-based SSP can serve as an effective instructional model in teacher education programs to prepare pre-service elementary school teachers with strong scientific literacy skills. These competencies are essential for addressing contemporary scientific challenges and improving the quality of science education in schools.

CONCLUSION

This study concludes that implementing Subject-Specific Pedagogy (SSP) based on the Technological Pedagogical Content Knowledge (TPACK) framework has a positive, significant effect on students' scientific literacy in science learning. The findings demonstrate a substantial improvement in students' scientific literacy, as reflected in the increase from the pre-test (medium category) to the post-test (very high category), supported by a moderate N-gain value and a statistically significant difference between pre-test and post-test scores. These results indicate that the structured integration of pedagogy, content, and technology through TPACK-based SSP effectively enhances students' understanding of scientific concepts, scientific reasoning skills, and their ability to relate science learning to real-life contexts. The impact of applying these research results is evident in their potential to guide the design of science learning in teacher education programs, particularly in preparing pre-service elementary school teachers with strong scientific literacy skills. Furthermore, the application of TPACK-based SSP can support lecturers and educational institutions in developing coherent, technology-integrated instructional practices that align learning objectives, learning activities, and assessment, thereby contributing to sustainable improvements in the quality of science teaching and learning at the elementary education level.

DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

CONFLICTING INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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