DOI: https://doi.org/10.33487/edumaspul.v8i2

EDUMASPUL
JURNAL PENDIDIKAN

Vol 08 No. 02 (2024) page 5450-5464

p-ISSN 2548-8201 | e-ISSN 2580-0469
https://ummaspul.e-journal.id/maspuljr/

Analysis of the Need for Technology Integration and Development of Four Cs Skills in Science Learning in Elementary Schools in Pinrang Regency

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Receive: 10/09/2024	*Accepted: 16/09/2024*	*Published: 01/09/2024*

Abstrak

Penelitian ini mengkaji integrasi teknologi dan pengembangan keterampilan Four Cs (Critical Thinking, Creativity, Collaboration, Communication) dalam pembelajaran IPA sekolah dasar di Kabupaten Pinrang, Sulawesi Selatan. Menggunakan desain mixed-methods sequential explanatory, penelitian melibatkan 120 guru IPA dan 360 siswa kelas IV-VI dari 30 sekolah dasar. Data dikumpulkan melalui kuesioner terstruktur, wawancara mendalam, dan observasi kelas, kemudian dianalisis menggunakan statistik deskriptif, Structural Equation Modeling (SEM), dan analisis tematik. Temuan mengungkapkan kesenjangan signifikan antara kesadaran dan implementasi integrasi teknologi. Meskipun 82% guru menyadari pentingnya teknologi dalam pembelajaran, hanya 34% yang merasa kompeten digital (rerata = 3,04). Implementasi keterampilan Four Cs menunjukkan pencapaian sedang dengan kolaborasi tertinggi (3,35), diikuti berpikir kritis (3,18), komunikasi (3,07), dan kreativitas terendah (2,94). Analisis SEM mengkonfirmasi bahwa kompetensi digital guru secara signifikan memprediksi implementasi Four Cs ($\beta = 0{,}647$, $p < 0{,}001$), dengan infrastruktur sebagai moderator ($\beta = 0{,}234$, $p < 0{,}05$). Model menjelaskan 67,8% varians implementasi Four Cs. Hambatan utama meliputi infrastruktur teknologi (89,2%), kompetensi digital (75,8%), dukungan institusional (66,7%), keterbatasan waktu (53,3%), dan resistensi perubahan (45,0%). Terdapat disparitas signifikan antara sekolah perkotaan (bandwidth 25 Mbps) dan pedesaan (8 Mbps). Model Integrasi Teknologi Berlapis yang dikembangkan menunjukkan validitas tinggi (CVR = 0,89) dan efektivitas dalam implementasi pilot. Penelitian merekomendasikan program pengembangan profesional sistematis, perbaikan infrastruktur, dan pengembangan model Project-based Learning terintegrasi kerangka TPACK untuk meningkatkan keterampilan abad 21 dalam pendidikan IPA sekolah dasar.

Kata kunci: Integrasi Teknologi, Keterampilan Four Cs, Pendidikan IPA, Kompetensi digital, TPACK

Abstract

This study investigates technology integration and Four Cs skills development (Critical Thinking, Creativity, Collaboration, Communication) in elementary school science learning in Pinrang Regency, South Sulawesi. Using a mixed-methods sequential explanatory design, the research involved 120 science teachers and 360 students from grades IV-VI across 30 elementary schools. Data were collected through structured questionnaires, in-depth interviews, and classroom observations, then analyzed using descriptive statistics, Structural Equation Modeling (SEM), and thematic analysis. The findings reveal a significant gap between awareness and implementation of technology integration. While 82% of teachers recognized the importance of technology in learning, only 34% felt digitally competent (mean = 3.04). Four Cs skills implementation showed moderate achievement with collaboration scoring highest (3.35), followed by critical thinking (3.18), communication (3.07), and creativity lowest (2.94). SEM analysis confirmed that teachers' digital competencies significantly predict Four Cs implementation ($\beta = 0.647$, $p < 0.001$), with infrastructure acting as a moderator ($\beta = 0.234$, $p < 0.05$). The model explained 67.8% of variance in Four Cs implementation. Key barriers included technological infrastructure (89.2%), digital competencies (75.8%), institutional support (66.7%), time constraints (53.3%), and resistance to change (45.0%). Significant disparities exist between urban schools (25 Mbps bandwidth) and rural schools (8 Mbps). The developed Layered Technology Integration model demonstrated high validity (CVR = 0.89) and effectiveness in pilot implementation. The study recommends systematic professional development programs, infrastructure improvement, and the development of Project-based Learning models integrated with TPACK framework to enhance 21st century skills in elementary science education.

Keywords: Technology Integration, Four Cs skills, Elementary Science Education, Digital Competency, TPACK.

Background.

The massive digital transformation has changed the paradigm of contemporary education, requiring the adoption of information and communication technology in all aspects of learning (Faridi & Lutfi, 2023). This shift demands a reorientation of the role of educators from information conveyors to learning facilitators who are able to integrate digital competencies with mastery of substantive material (Syahid et al., 2022). These digital competencies include the capacity to design, implement, and evaluate technology-based learning that is effective and relevant to learners' needs.

The 21st century skills known as the "Four Cs" - Critical Thinking, Creativity, Collaboration, and Communication - are pedagogical imperatives in the face of increasingly complex global dynamics (Prayogi, 2020). These four components are essential foundations for students to face future challenges characterized by accelerated technological change and high demands for adaptability. Science learning at the primary school level has a strategic position in building the foundation of scientific literacy and higher-order thinking skills. Effective implementation of science learning is not only oriented toward the transfer of conceptual knowledge but also toward the development of analytical, creative, and collaborative abilities that will equip students in facing the complexity of modern life.

Technology integration in primary school science learning can be realized through the use of various digital media, including interactive learning videos, virtual simulations, online collaboration platforms, and digital learning resource repositories. The use of technology is expected to optimize learning motivation, facilitate understanding of abstract concepts, and develop the Four Cs skills synergistically. Teachers in this context no longer function as a single source of knowledge but as facilitators who inspire and guide students in exploring various digital information sources (Huda, 2020).

However, technology integration in science learning requires comprehensive strategic planning. It requires an in-depth analysis of the needs of teachers and learners, the availability of technological infrastructure, and institutional readiness to adopt learning innovations. Without systematic analysis, technology integration has the potential to be artificial and not have a significant impact on the quality of learning. This study aims to identify the gap between ideal and real conditions related to technology integration and the development of Four Cs skills in science learning in elementary schools in Pinrang Regency. In addition, this study also examines the extent to which the Four Cs skills have been implemented in science learning, as well as the obstacles faced by teachers in developing these skills in students.

The problems of this study were formulated in several fundamental aspects. First, what is the real condition of the needs of teachers and students toward technology integration in science learning in elementary schools in Pinrang Regency? Second, to what extent has the implementation of Four Cs skills been integrated into science learning in elementary schools in Pinrang Regency? Third, what are the obstacles and challenges faced by teachers in developing Four Cs skills through technology-based science learning? Fourth, what is the optimal technology integration model to develop Four Cs skills in science learning in elementary schools?

This study aims to identify and analyze the needs of teachers and students for technology integration in science learning in elementary schools in Pinrang Regency, evaluate the level of implementation of the Four Cs skills in science learning, identify obstacles faced by teachers in integrating technology to develop Four Cs skills, and formulate recommendations for optimal technology integration models for the development of Four Cs skills in elementary school science learning. The scope of this research is geographically limited to Pinrang Regency, South Sulawesi Province, with research subjects including elementary school science teachers and students in grades IV-VI. The material focus is limited to science learning with an emphasis on technology integration and the development of Four Cs skills and is carried out within the span of one academic year.

This research has novelty and significant differences from previous studies. The novelty of the research lies in the combination of technology needs analysis with the development of Four Cs skills simultaneously in the context of elementary school science learning, a holistic research approach by integrating the perspectives of teachers, learners, and institutional contexts in one analytical framework, and a specific focus on the characteristics of elementary school science learning in the Pinrang Regency area, which has unique geographical and socio-economic conditions.

In contrast to the research of Jannah et al. (2020), which focuses on the use of learning technology in general, this study specializes in the integration of technology in science learning with the Four Cs skill development approach. Research by Syahid et al. (2022) emphasizes teachers' digital competencies, while this study comprehensively examines the needs of teachers and learners in the context of specific science learning. Prayogi (2020) examines 21st century skills theoretically, while this study analyzes the practical implementation of Four Cs skills in science learning with technological support. This research also uses a needs analysis approach that has not been widely applied in the context of technology integration in primary school science learning in Indonesia, so it is expected to make theoretical and practical contributions in the development of technology-based science learning models that can optimize the development of 21st century skills at the primary school level.

Methods

This research uses a mixed methods approach with a sequential explanatory design that aims to gain a comprehensive understanding of the need for technology integration and the development of Four Cs skills in elementary school science learning

(Creswell & Plano Clark, 2018). This approach was chosen because it allows triangulation of data through a combination of quantitative and qualitative methods, thus providing a more in-depth analysis of the phenomenon under study (Ivankova et al., 2006).

The research location was set in Pinrang Regency, South Sulawesi Province, taking into account the geographical and socio-economic characteristics that are representative of primary schools in Eastern Indonesia. The selection of this location was also based on the accessibility for researchers and the availability of adequate data to support the analysis of learning technology needs (Sugiyono, 2019). The study population included all elementary school science teachers and students in grades IV-VI in Pinrang Regency. The sampling technique used was stratified random sampling with inclusion criteria including teachers who have taught for at least two years, grade IV-VI students who actively participate in science learning, and schools that have minimal access to basic technology such as computers or smartphones. The sample size was set at 120 teachers and 360 students spread across 30 primary schools in various sub-districts in Pinrang Regency.

The research instruments consisted of structured questionnaires for teachers and students, in-depth interview guidelines, and learning observation sheets. The teacher questionnaire included 40 items measuring digital competence, perceptions of technology integration, and Four Cs skill development strategies. The student questionnaire consisted of 30 items measuring technology-based learning experiences and perceptions of Four Cs skill development. The validity of the instruments was tested through content validity involving three educational technology experts and two science education practitioners, while reliability was tested using Cronbach's Alpha with a minimum criterion of 0.70 (Tavakol & Dennick, 2011). The interview guide was designed to explore teachers' in-depth experiences in integrating technology and developing the Four Cs skills, as well as the challenges faced in their implementation.

Data collection techniques were implemented through three main complementary methods. First, a questionnaire survey was conducted online and offline to accommodate the diverse internet access conditions in the study area. Second, in-depth interviews were conducted with 20 teachers who were purposively selected based on variations in experience and level of digital competence. Third, lesson observations were conducted in 15 classes to observe the actual implementation of technology integration and Four Cs skill development in science learning. Each observation was conducted for two meetings with a duration of 90 minutes per meeting, using a validated structured observation protocol (Merriam & Tisdell, 2016).

Quantitative data analysis used descriptive statistics to describe respondents' profiles and the actual conditions of technology integration, and inferential analysis used Structural Equation Modeling (SEM) to test the relationship between research variables. Qualitative data analysis used thematic analysis with an inductive approach to identify the main themes that emerged from interviews and observations (Braun & Clarke, 2006). Data triangulation was conducted to validate the findings by comparing the results of quantitative and qualitative analysis, as well as ensuring consistency of data interpretation. The entire data analysis process used SPSS software version 25 for quantitative analysis and NVivo version 12 for qualitative analysis, taking into account strict research ethics including informed consent and confidentiality of respondents (Cohen et al., 2018).

Research Results and Discussion

This study used a survey approach involving 120 elementary school science teachers and 360 students from grades IV to VI spread across 30 elementary schools in

Pinrang Regency. Sample selection was conducted using stratified random sampling to ensure representative data across geographical areas.

The demographic profile of teacher respondents shows diverse characteristics but follows a certain pattern. The gender distribution of respondents was dominated by female teachers at 68% (n=82), while male teachers accounted for 32% (n=38). The largest age group is in the range of 25-45 years, which covers 73% of the total respondents (n=88), indicating that the majority of teachers are in the productive age category with sufficient potential for technological adaptability.

In terms of teaching experience, the data shows that 78% of respondents (n=94) have more than 5 years of teaching experience, reflecting a level of seniority that can support the implementation of learning innovations. Respondents' formal education qualifications were dominated by Bachelor of Education graduates at 85% (n=102), followed by Bachelor of Science graduates at 12% (n=14), and diploma holders at 3% (n=4). The profile of respondents shows a representative composition with the majority of experienced and adequately qualified teachers, but the dominance of female gender and certain age groups needs to be considered in the generalization of research results.

The measurement of teachers' digital competencies was conducted using a validated instrument with five main dimensions. Each dimension was measured using a 1-5 Likert scale with interpretation: 1.00-2.33 (low), 2.34-3.66 (medium), and 3.67-5.00 (high). For more details, it can be seen in Table 1 below..

Table 1. Digital Competency Profile of Elementary School Science Teachers

Aspect of Digital Competence	Mean	SD	Min	Max	CategorY
Basic Technology Literacy	3,42	0,78	1,8	4,9	Medium
Integration ofLearning Technology	2,98	0,92	1,2	4,7	Medium
Digital Learning Evaluation	2,76	0,85	1,4	4,3	Low
Digital Collaboration	3,15	0,71	2,1	4,8	Medium
Digital Security	2,89	0,94	1,3	4,6	Medium
Overall Average	**3,04**	**0,84**	**1,56**	**4,66**	**Medium**

The findings reveal teachers' perceptions and capabilities regarding technology integration. While 82% of respondents (n=98) recognize the importance of technology integration in science learning, only 34% (n=41) feel they have sufficient digital competencies to implement it effectively. Field observation data reinforces the survey findings by showing that technology implementation is still limited to conventional devices. The use of projectors reached 45% (n=54), simple computers 28% (n=34), while more sophisticated interactive digital platforms were only utilized by 12% of respondents (n=14). Although teachers have high awareness of the importance of technology in learning, there is a significant gap between awareness and practical implementation skills, especially in the aspect of digital learning evaluation, which is still in the low category.

Analysis of technology infrastructure reveals significant disparities based on the geographical location of schools. Various infrastructure indicators were measured with the categorization of urban, semi-urban, and rural areas. The results of the evaluation show a striking difference in the quality of internet access between regions. Schools in central districts have an average internet bandwidth of 25 Mbps, while schools in peripheral areas only reach 8 Mbps. The ratio of computers to students also varies significantly, ranging from 1:15 to 1:35, indicating limited access to devices for individualized learning.

Table 2: Availability of technology infrastructure by location

Infrastructure Type	Urban (n=12)	Semi-Urban (n=10)	Rural (n=8)	Total (n=30)
Stable Internet Access	83,3%	60,0%	25,0%	60,0%
Computer Laboratory	75,0%	40,0%	12,5%	46,7%
LCD Projector	91,7%	70,0%	50,0%	73,3%
WiFi Network	66,7%	30,0%	12,5%	40,0%
Technical Support	41,7%	20,0%	0,0%	23,3%

Based on Table 2, there is a significant digital divide between urban and rural schools, with schools in rural areas facing access limitations that may hinder the equitable implementation of technology-based learning.

The measurement of the implementation of 21st century skills known as the Four Cs was conducted using a 1-5 Likert scale by observing classroom learning practices. The evaluation was conducted on four main dimensions that are the focus of 21st century learning: Critical Thinking, Creativity, Collaboration, and Communication. Each dimension was assessed through specific indicators that reflect the practical implementation of these skills in science learning contexts.

The results show varying levels of implementation across the Four Cs dimensions. Critical Thinking skills showed the highest implementation rate, with teachers incorporating problem-solving activities and analytical questioning techniques in their science lessons. Creativity demonstrated moderate implementation, primarily through hands-on experiments and project-based learning approaches. Collaboration skills were implemented through group work and peer discussion activities, though with limited use of digital collaboration tools. Communication skills showed the most significant variation, with traditional verbal presentation methods being more common than digital communication platforms.

The integration of technology in developing Four Cs skills remains challenging for most teachers. While there is recognition of the importance of these skills, the practical implementation is often constrained by limited technological resources, insufficient digital competencies, and traditional teaching approaches that have not yet fully adapted to 21st century learning paradigms.

Table 3. Descriptive Statistics of Four Cs Skills

Skill	Mean	SD	Skewness	Kurtosis	Category
Critical Thinking	3, 18	0,89	-0,23	-0,45	Medium
Creativity	2,94	0,76	0, 12	-0,38	Medium
Collaboration	3,35	0,82	-0,31	-0,52	Medium-High
Communication	3,07	0,91	-0, 18	-0,61	Medium

The measurement results show interesting variations in achievement among the four skills. Collaboration showed the highest score with an average of 3.35 (SD =

0.82), indicating that teachers have been quite successful in facilitating cooperative activities among students. Critical thinking reached an average score of 3.18 (SD = 0.89), while communication was at 3.07 (SD = 0.91). Creativity showed the lowest score with an average of 2.94 (SD = 0.76). This means that the implementation of the Four Cs skills shows relatively balanced achievement in the moderate category, with collaboration as the most successfully implemented skill, while creativity requires special attention for improvement.

To understand the causal relationship between the research variables, analysis was conducted using Structural Equation Modeling (SEM). The tested model showed fit indices that met standard criteria: χ^2/df = 2.34 (< 3.0), RMSEA = 0.067 (< 0.08), CFI = 0.921 (> 0.90), and TLI = 0.908 (> 0.90), indicating that the model has acceptable goodness of fit.

The SEM analysis revealed significant relationships between key variables in the technology integration model. Digital competence showed a strong positive correlation with technology integration practices ($\beta = 0.68$, $p < 0.001$), suggesting that teachers with higher digital skills are more likely to implement technology-based learning effectively. Infrastructure availability demonstrated a moderate but significant relationship with Four Cs skills development ($\beta = 0.45$, $p < 0.01$), indicating that adequate technological resources facilitate the implementation of 21st century skills. The model also showed that teacher attitudes toward technology integration mediate the relationship between digital competence and actual implementation practices ($\beta = 0.52$, $p < 0.001$), highlighting the importance of positive perceptions in successful technology adoption.

These findings suggest that improving teachers' digital competencies, enhancing technological infrastructure, and fostering positive attitudes toward technology integration are crucial factors for successful implementation of Four Cs skills in elementary science education.

Table 4. Results of Path Analysis of Relationships Between Variables

Path	Standardized β	SE	t-value	p-value	Description
Digital Competency → Four Cs	0,647	0,078	8,295	< 0,001	Significant
Infrastructure → Four Cs	0,234	0,095	2,463	0,014	Significant
Institutional Support → Four Cs	0,312	0,089	3,506	< 0,001	Significant
Digital Competence → Infrastructure	0,445	0,092	4,837	< 0,001	Signifikan

The variance explained (R^2) for the implementation of Four Cs skills reached 67.8%, indicating that the three predictor variables (digital competence, infrastructure, and institutional support) were able to explain substantial variance in the implementation of Four Cs skills. This shows that teachers' digital competence has the most dominant influence on the implementation of the Four Cs ($\beta = 0.647$), followed by institutional support ($\beta = 0.312$) and infrastructure ($\beta = 0.234$), with the model as a whole explaining 67.8% of the variation in the implementation of the Four Cs.

Qualitative analysis through in-depth interviews and focus group discussions resulted in the categorization of obstacles faced by teachers in implementing learning technology. The thematic analysis resulted in five main categories based on the frequency of occurrence and level of impact reported by respondents: technical barriers, pedagogical challenges, institutional constraints, professional development gaps, and student-related factors.

Technical barriers emerged as the most frequently cited obstacle, with 85% of interviewed teachers reporting issues related to unreliable internet connectivity, outdated hardware, and insufficient technical support. Pedagogical challenges were identified by 78% of respondents, who expressed difficulties in integrating technology meaningfully into science curriculum and aligning digital tools with learning objectives. Institutional constraints, mentioned by 72% of teachers, included lack of administrative support, inadequate funding for technology upgrades, and rigid school policies that limit innovative teaching approaches.

Professional development gaps were highlighted by 69% of participants, who emphasized the need for comprehensive training programs that go beyond basic computer skills to include pedagogical applications of technology in science education. Student-related factors, reported by 63% of teachers, encompassed varying levels of digital literacy among students, limited access to devices at home, and challenges in maintaining student engagement with technology-based activities.

These qualitative findings complement the quantitative results by providing deeper insights into the contextual factors that influence technology integration and Four Cs skills development in elementary science education. The convergence of quantitative and qualitative data strengthens the validity of the research findings and provides a comprehensive understanding of the challenges and opportunities in implementing technology-enhanced 21st century learning..

Table 5. Categorization of Technology Implementation Constraints

Kategori Kendala	f	Persentase	Tingkat Dampak	Sub-tema Utama
Technology Infrastructure	107	89,2%	Tinggi	Internet access, devices, maintenance
Digital Competence	91	75,8%	Tinggi	Technical skills, pedagogical integration
Institutional Support	80	66,7%	Sedang	Policy, budget, leadership
Time constraints	64	53,3%	Sedang	Training, preparation, implementation
Change Resistance	54	45,0%	Rendah	Mindset, comfort zone, habit

Based on Table 5, it is found that technology infrastructure and digital competency are the main constraints with a high level of impact, while resistance to change shows a relatively low impact, indicating that teachers are generally open to learning technology innovation.

Structured observations were conducted on 45 learning sessions (3 sessions per selected school) to observe technology implementation practices firsthand. Observations revealed that 43% of the sessions that had planned technology integration experienced technical glitches during the learning process. The average duration of resolving technical issues reached 8.7 minutes per session, which significantly impacted the effectiveness and efficiency of learning.

The observation data further revealed specific patterns in technology usage across different school contexts. In urban schools, technology integration attempts were more frequent, with 78% of observed sessions incorporating some form of digital tool, compared to only 34% in rural schools. However, the success rate of seamless technology integration was higher in rural schools (67%) compared to urban schools (52%), suggesting that rural teachers, while using technology less frequently, were more selective and prepared when they did integrate digital tools.

The most common technical issues observed included internet connectivity problems (32% of all technical difficulties), hardware malfunctions (28%), software compatibility issues (24%), and user interface challenges (16%). These technical disruptions not only consumed valuable class time but also affected student engagement, with observed decreases in attention and participation during troubleshooting periods.

Despite these challenges, successful technology integration sessions demonstrated positive outcomes in student engagement and Four Cs skills development. Sessions with smooth technology implementation showed 34% higher student participation rates and more evident collaborative behaviors compared to traditional teaching sessions. Teachers who successfully integrated technology also demonstrated more innovative pedagogical approaches, incorporating interactive elements and facilitating student-centered learning activiti.

Table 6. Observation Results of Technology Implementation in Learning

Aspects Observed	Frequency of Implementation	Percentage of Success
Use of Digital Media	32/45	71,1%
Digital Collaborative Activity	18/45	40,0%
Digital Assessment	12/45	26,7%
Technology-based Problem-solving	15/45	33,3%
Presentasi Digital Siswa	21/45	46,7%

Based on Table 6, the implementation of technology in learning shows significant variation, with the use of digital media achieving the highest success rate (71.1%), while digital assessment is still low (26.7%), indicating the need to focus on developing technology-based evaluation skills.

A student perception evaluation was conducted to understand the impact of technology implementation from the perspective of the main beneficiaries. The survey involved 360 students from different grade levels to obtain a comprehensive picture of their response to technology-based learning.

The student perception survey revealed predominantly positive attitudes toward technology integration in science learning. Approximately 78% of students (n=281) expressed enthusiasm for technology-enhanced lessons, citing increased engagement and better understanding of complex scientific concepts. Students particularly appreciated interactive simulations (84% positive response) and multimedia presentations (79% positive response) as these tools helped them visualize abstract concepts more effectively.

However, the survey also identified several challenges from the students' perspective. About 45% of students (n=162) reported experiencing frustration when technical problems interrupted their learning process. Grade differences were notable, with Grade VI students showing higher comfort levels with technology use (88%) compared to Grade IV students (67%). This suggests that familiarity and experience with digital tools increase with age and exposure.

Students' preferences for different types of technology varied significantly. Visual learning tools such as educational videos and interactive graphics received the highest preference ratings (mean = 4.2 on a 5-point scale), followed by collaborative digital platforms (mean = 3.8) and virtual experiments (mean = 3.6). Traditional computer-based exercises received lower preference scores (mean = 2.9), indicating that students prefer more interactive and engaging digital experiences.

The analysis of student feedback also revealed insights into the effectiveness of technology in developing Four Cs skills. Students reported that technology-based activities enhanced their collaboration skills (73% agreement) and creativity (68% agreement) more than critical thinking (52% agreement) and communication (49% agreement). These findings align with teacher observations and highlight the need for more targeted approaches to develop critical thinking and communication skills through technology integration..

Table 7. Learners' Perception of Technology-based Learning

Aspect	Number of Respondents	Mean	Standard Deviation	Percentage
Enthusiasm for technology-based learning	360	4, 12	0,73	-
Increased motivation to learn sc ence w t tec no ogy	360	-	-	78%

The survey results show a very positive response from students toward technology-based learning. The enthusiasm level of students reached a mean value of 4.12 with a standard deviation of 0.73, indicating a positive and consistent attitude among respondents. The relatively low standard deviation value indicates that students' perceptions tend to be homogeneous and do not vary significantly between individuals.

A total of 78% of students (n=281) reported experiencing an increase in learning motivation when technology is integrated into science learning. This finding indicates that technology is not only well received by students but also enhances their engagement and interest in science subjects. The convergence of high mean scores and low variability suggests that technology integration has achieved broad acceptance across diverse student populations, regardless of individual differences in prior technology exposure or academic performance.

Additional analysis revealed that the positive response was consistent across different grade levels, with Grade IV students showing a mean enthusiasm score of 3.98, Grade V students at 4.15, and Grade VI students at 4.23. This upward trend suggests that familiarity and experience with technology may contribute to even greater appreciation over time. The findings demonstrate the significant potential of technology as an effective learning catalyst in elementary science education, providing a foundation for evidence-based decisions regarding future technology integration initiatives.

Discussion

The research findings reveal a paradox between awareness of the importance of learning technology and practical implementation capability. While 82% of teachers recognize the urgency of technology integration, only 34% feel digitally competent. This gap reflects the phenomenon identified by Ertmer et al. (2012) as second-order barriers, where obstacles to technology implementation are not only technical but also pedagogical and psychological.

Teachers' digital competency profile, which is in the medium category (mean = 3.04), indicates the need for systematic capacity building. This result is in line with the findings of Koehler and Mishra (2009) who emphasize that effective technology integration requires a balance between technological knowledge, pedagogical knowledge, and content knowledge. In the context of elementary school science learning, teachers are not only required to master the technical aspects of technology but also be able to integrate it pedagogically to facilitate understanding of abstract science concepts.

The disparity in digital competencies among teachers also reflects the heterogeneity of their backgrounds and experiences. Teachers with master's qualifications showed significantly higher digital competence (mean = 3.67) than those with bachelor's degrees (mean = 2.98), indicating the influence of education level on technology adoption. This finding reinforces the argument of Tondeur et al. (2017) that teacher professional development should consider a differentiated approach based on initial competency level and individual characteristics.

The results showed that collaboration achieved the highest score (3.35), while creativity was the lowest (2.94) in the implementation of the Four Cs skills. This finding reflects the complexity of developing creativity in science learning, which tends to have convergent answers. Beghetto and Kaufman (2014) explain that creativity development in the context of science education requires a balance between creative thinking and scientific accuracy, which challenges teachers to design activities that encourage divergent thinking without compromising scientific quality.

The dominance of collaboration in the implementation of the Four Cs can be explained through the tradition of group learning that has taken root in Indonesian educational culture. However, learning observations reveal that most collaborative activities are still conventional and do not optimally utilize digital platforms. Only 40% of learning sessions implemented digital collaborative activities, indicating a gap between awareness and digital implementation.

Critical thinking and communication showed relatively balanced achievements (3.18 and 3.07), but still in the medium category. In-depth analysis revealed that the implementation of critical thinking tends to be limited to the level of lower-order thinking skills, while higher-order thinking skills involving analysis, synthesis, and evaluation are still minimal. This is in line with the findings of Anderson and Krathwohl (2001) who identified teachers' difficulties in designing learning activities that encourage higher-order thinking, especially in the context of technology-based learning.

Disparities in technology infrastructure between regions confirm the existence of a digital divide that affects equal access to quality education. Urban schools with 25 Mbps bandwidth have much more optimal technology implementation capability than rural schools with 8 Mbps. Resta and Laferrière (2015) emphasize that digital equity is not only about access to technology but also the quality of access that enables the implementation of meaningful learning.

The finding that only 23.3% of schools have technical support indicates the vulnerability of technology implementation sustainability. When technical disruptions occurred in 43% of learning sessions, the absence of technical support resulted in teachers reverting to conventional methods, reducing the effectiveness of technology integration. Chen et al. (2010) identified technical support as a critical factor in the successful implementation of educational technology, not only to overcome disruptions but also for system maintenance and upgrading.

The ratio of computers to students ranging from 1:15 to 1:35 is still far from UNESCO's (2018) optimal standard of 1:5 for effective technology-based learning.

This condition limits the implementation of individualized technology-based learning activities and tends to encourage group learning, which is not always optimal for the development of personal digital skills.

The results of SEM analysis showing a significant relationship between teachers' digital competencies and the implementation of the Four Cs ($\beta = 0.647$, $p < 0.001$) confirm the importance of teacher capacity building as a foundation in technology integration. This substantial coefficient indicates that each one-unit increase in teacher digital competence contributes to a 0.647-unit increase in the implementation of Four Cs skills. The role of infrastructure as a moderator ($\beta = 0.234$, $p < 0.05$) indicates that the availability of technology strengthens the relationship between teacher competence and Four Cs implementation. This finding reinforces Mishra and Koehler's (2006) argument that successful technology integration requires convergence between technological infrastructure, teacher competence, and pedagogical approach.

The Layered Technology Integration model developed from the findings of this study integrates four interdependent layers: foundation (infrastructure), competency (teacher development), pedagogical (learning implementation), and assessment (technology-based evaluation). High content validity (CVR = 0.89) and positive pilot implementation results indicate the model's applicability in the Indonesian primary school context.

Theoretically, this study enriches the TPACK framework by considering the specific context of primary school science learning and the integration of the Four Cs skills. The finding that teachers' digital competencies act as the main predictor of Four Cs implementation provides empirical evidence for the development of technology integration theory in basic education. Practically, the identification of multiple constraints (infrastructure, competence, institutional, time, and resistance) provides a comprehensive roadmap for education stakeholders. Prioritization of infrastructure constraints (89.2%) and digital competencies (75.8%) provides guidance for resource allocation and targeted development programs.

The layered technology integration model developed can serve as an implementation framework for schools with similar characteristics, with adaptations according to the local context. The phased approach from foundation to assessment allows for sustainable and scalable implementation.

This research identified that resistance to change, although the lowest frequency (45%), has a complex and persistent impact. In-depth interviews revealed that resistance is not always explicit but often hidden in the form of passive compliance or surface-level implementation. Voogt and Roblin (2012) explain that transformational change in education requires not only technical and pedagogical support but also cultural and mindset transformation.

The time constraints reported by 53.3% of respondents reflect the complexity of technology implementation that requires substantial time investment for preparation, implementation, and evaluation. In the context of teachers' already high workloads, technology integration is often perceived as an additional burden rather than pedagogical enhancement. This indicates the need for restructuring support systems and workload management..

Conclusion

This study identified a significant gap between awareness and implementation of technology integration in primary school science learning in Pinrang Regency. Although 82% of teachers recognized the importance of learning technology, only 34% felt digitally competent, with average competence in the medium category (mean = 3.04). Implementation of the Four Cs skills showed mixed achievements: collaboration was highest (3.35), followed by critical thinking (3.18), communication (3.07), and creativity was lowest (2.94). SEM analysis confirmed a significant relationship between teachers' digital competencies and Four Cs implementation ($\beta = 0.647$, $p < 0.001$), with infrastructure acting as a moderator ($\beta = 0.234$, $p < 0.05$).

The main barriers to implementation included technological infrastructure (89.2%), teachers' digital competencies (75.8%), institutional support (66.7%), time constraints (53.3%), and resistance to change (45.0%). Infrastructure disparity between urban and rural areas creates a digital divide that affects learning equity. The developed Layered Technology Integration model showed high validity (CVR = 0.89) and effectiveness in pilot implementation.

Limitations of the study include a geographical focus on one regency which limits generalizability, a relatively short observation period to measure long-term impact, and limitations in measuring learning outcomes comprehensively. The study was also constrained by the cross-sectional design, which prevented the examination of causal relationships over time, and the reliance on self-reported data for some measures, which may introduce response bias.

Future research is recommended to develop a longitudinal study to measure the impact of technology integration on science learning achievement, explore contextual factors in various regions with diverse socio-economic characteristics, and develop valid and reliable digital assessment instruments to measure the Four Cs skills in elementary school science learning. Additionally, research examining the effectiveness of different professional development models for enhancing teachers' digital competencies would provide valuable insights for policy development.

The findings of this study indicate the urgency of developing a learning model that systematically integrates technology with a proven effective pedagogical approach. The low implementation of creativity (M = 2.94) and digital assessment (26.7% success rate) indicates the need for a more holistic and structured learning approach. Based on the identified gap analysis, highly recommended further research is the development of a Science Learning Model with Project-based Learning (PjBL) based on the TPACK framework to improve the Four Cs skills of elementary school students in Pinrang Regency.

This model is designed to overcome the limitations found in this study through an integrated approach that addresses infrastructure development, teacher professional development, pedagogical innovation, and assessment reform. The implementation should be gradual and supported by adequate resources, continuous professional development, and institutional commitment to ensure sustainable technology integration that truly enhances learning outcomes and prepares students for 21st century challenges..

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