
TEACHER DIGITAL COMPETENCE AND STEM EDUCATION IMPLEMENTATION IN LOWER SECONDARY SCHOOLS: EVIDENCE FROM A SURVEY STUDY

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ABSTRACT

This study examines teacher competencies and the development of STEM education in lower secondary schools within the context of digital transformation and the application of artificial intelligence (AI). Teacher competence is evaluated based not only on the ability to use technology but also on the capacity to effectively integrate technology into pedagogical practice. Data were collected from teachers via questionnaires focusing on the utilization of digital resources, technology- and AI-supported STEM lesson design, digital assessment, and student monitoring and support. The results indicate a high level of engagement with digital resources; however, the integration of technology and AI into lesson design, assessment, and student support remains inconsistent. The study suggests a need to enhance teachers' digital pedagogical competencies by aligning technology and AI with STEM teaching practices.

KEYWORDS: Teacher competence; STEM education; digital transformation; artificial intelligence; technology integration; secondary education.

INTRODUCTION

Digital transformation is significantly changing the way teaching and learning are organized in schools, particularly in STEM education, where students are expected to engage in activities involving exploration, hands-on practice, data analysis, and real-world problem solving. The development of digital platforms, electronic learning resources, simulation

software, data visualization tools, and artificial intelligence (AI) is creating new possibilities for designing and organizing STEM learning activities.

In this context, teachers' digital competence has become an important condition for the implementation of STEM education. According to Redecker (2017), educators' digital competence involves not only the ability to operate technological tools but also the capacity to select and use technology to design teaching and learning activities, assess students, and provide learner support [5]. In STEM education, this is reflected in teachers' ability to leverage technology to develop learning tasks, support students in collecting and analyzing data, simulate phenomena, design products, and collaboratively solve problems.

STEM education has become increasingly prominent at the lower secondary school level. Teachers are expected not merely to use technology for presentations or information delivery but also to leverage technology to support students in observing phenomena, collecting and processing data, simulating processes, designing products, collaborating, and testing solutions. The emergence of artificial intelligence further expands teachers' roles in designing learning tasks, developing and using instructional materials, providing feedback, and guiding students toward responsible technology use.

However, technical proficiency in using technology does not necessarily translate into the effective integration of technology into STEM pedagogical practice. This gap highlights the need to examine teachers' digital competence not only in terms of their ability to use technological tools but also in terms of how technology is applied in the design, organization, and assessment of STEM activities. Particularly at the lower secondary school level, further empirical evidence is needed regarding the relationship between teachers' digital competence and the implementation of STEM education.

Based on these issues, this study examines teachers' digital competence and the implementation of STEM education in lower secondary schools, focusing on the following aspects: the use of digital resources; the design of technology- and AI-supported STEM activities; digital assessment; and monitoring and supporting students. On this basis, the study identifies patterns of technology use and gaps in the process of integrating technology into STEM pedagogical practice.

1. INTRODUCTION

1.1. Digital Transformation and AI in STEM Education

Digital transformation is significantly changing the way teaching and learning are organized, particularly in STEM education, where students are expected to apply knowledge to observe

phenomena, conduct experiments, analyze data, and solve real-world problems. The development of online learning platforms, digital resources, simulations, virtual laboratories, and data visualization tools provides additional opportunities for students to engage in interactive and hands-on learning activities. Therefore, technology is no longer used merely to present content but is increasingly becoming an integral component of STEM activity design and implementation. UNESCO (2023) emphasizes that the educational value of technology depends considerably on how it is integrated into teaching and learning processes and on teachers' capacity to use it effectively [8].

The rapid development of artificial intelligence (AI) has further expanded the possibilities for technology integration in STEM education. AI can support teachers in developing learning tasks, creating instructional materials, analyzing data, and providing feedback, while also supporting students in searching for information, generating ideas, and refining solutions. However, the use of AI in education requires teachers not only to possess technical skills but also to select appropriate tools, verify information, guide students toward responsible AI use, and ensure adherence to ethical principles. The AI Competency Framework for Teachers (Miao & Cukurova, 2024) emphasizes that AI competence should be grounded in a human-centered approach, ethics, pedagogy, and professional development [3].

Thus, digital transformation and AI are changing the expectations placed on teachers in the implementation of STEM education. The issue is no longer simply whether teachers use technology, but, more importantly, how technology is integrated into the design and organization of STEM pedagogical activities. This provides a basis for examining teachers' digital competence not merely from a technical perspective but in direct relation to STEM teaching practices at the lower secondary school level.

1.2. The Changing Role of Teachers

Digital transformation and the development of artificial intelligence are changing the role of teachers in STEM education. Whereas teachers previously focused primarily on transmitting knowledge and guiding learning activities, in digital learning environments they increasingly serve as designers, organizers, facilitators, and supporters of the learning process. Teachers need to select technologies that are appropriate to the objectives, content, and characteristics of STEM tasks, while creating opportunities for students to actively explore, collaborate, experiment, and solve problems. According to DigCompEdu, teachers' digital competence is reflected not only in their ability to use technological tools but also in their capacity to leverage technology to design teaching and learning activities, assess students, and provide learner support [5].

In STEM teaching, the teacher's design role is particularly important because technology generates educational value only when it is embedded within an appropriate pedagogical strategy. Teachers need to determine which tools genuinely support learning objectives rather than using technology merely to increase the visual appeal or perceived modernity of a lesson. This requires the integration of subject knowledge, pedagogical knowledge, and technological understanding to develop learning tasks connected to real-world problems, encourage students to collect data, analyze information, design products, and test solutions.

The development of AI further expands the teacher's role toward guiding, monitoring, and verifying technology use. Teachers need to guide students in evaluating the reliability of AI-generated information, recognizing the limitations of AI tools, and using AI appropriately in relation to learning objectives. The AI Competency Framework for Teachers emphasizes human-centered thinking, AI ethics, AI applications, AI pedagogy, and professional development. This indicates that teachers cannot simply be users of AI tools; rather, they need to make informed decisions about when, why, and how AI should be used in the teaching and learning process.

Therefore, the changing role of teachers in STEM education can be reflected in three main dimensions: designing learning activities that integrate technology; facilitating and supporting the learning process; and guiding the effective and responsible use of technology and AI. This transformation suggests that the development of teachers' digital competence should be directly connected to STEM pedagogical practice rather than focusing solely on their ability to operate technological tools.

1.3. Research Gap: From Technology Use to Technology Integration into STEM Pedagogy

The widespread availability of digital tools in education does not necessarily mean that teachers are able to integrate technology effectively into STEM teaching. Teachers may use online platforms, software, digital resources, or AI tools, but technical proficiency is only one component of digital competence. Teachers' digital competence also includes the ability to select, design, and use technology to support teaching and learning, assessment, and the development of learners' competencies.

This gap is particularly noteworthy in STEM education because technology integration requires teachers to connect technology, content, and pedagogy within specific learning tasks. Technology creates meaningful educational value only when it supports students in exploring problems, collecting and analyzing data, conducting simulations, designing products, collaborating, and testing solutions. The TPACK framework proposed by Mishra and

Koehler argues that meaningful technology use in teaching depends on the interaction among technological knowledge, content knowledge, and pedagogical knowledge rather than on independent mastery of technological tools [4].

As AI develops rapidly, the gap between technology use and technology integration into pedagogy has become increasingly apparent. Teachers may use AI to generate questions, instructional materials, or content, but this does not necessarily ensure that AI is appropriately integrated with the objectives and processes of STEM activities. Teachers also need to evaluate AI-generated information, determine an appropriate level of AI support, and guide students toward responsible AI use. Therefore, teachers' AI competence encompasses dimensions related to an ethical foundation, AI foundations and applications, AI pedagogy, and professional development.

Although research on teachers' digital competence has expanded considerably, further empirical evidence is needed regarding the gap between teachers' ability to use technology and their ability to integrate technology into STEM pedagogical practice, particularly at the lower secondary school level. This research gap provides a basis for examining not only the extent to which teachers use technology but also how they use digital resources, design technology- and AI-supported STEM activities, conduct digital assessment, and support students throughout the learning process.

1.4. Research Objectives and Research Questions

This study aims to examine the extent and ways in which lower secondary school teachers apply digital technology and artificial intelligence (AI) in implementing STEM education, focusing on the following activities: using digital resources, designing STEM activities, organizing interaction and supporting students, monitoring learning processes, and conducting assessment and evaluation. This approach conceptualizes digital competence not merely as the ability to operate technological tools but also as the ability to integrate technology into specific pedagogical activities to support STEM teaching and learning (Redecker, 2017) [5].

Accordingly, the study examines the application of technology and AI across a sequence of preparation – design – organization – monitoring – support – assessment, thereby identifying aspects in which teachers appear to apply technology relatively readily and aspects that remain more limited. Particular attention is given to the difference between the ability to design technology- and AI-supported STEM activities and the ability to use technology and AI to monitor, provide feedback, assess, and support students during the learning process. Based on this objective, the study addresses four research questions:

RQ1. To what extent do lower secondary school teachers use digital resources and apply technology and AI in the design and organization of STEM education?

RQ2. How do teachers use digital technology and AI in lesson design, interaction, student support, and assessment during the implementation of STEM tasks?

RQ3. What differences can be observed between the design of technology- and AI-supported STEM activities and the monitoring, feedback, assessment, and support of students during the learning process?

RQ4. What implications do the survey findings suggest for developing teachers' digital competence to enhance the implementation of STEM education at the lower secondary school level?

The four research questions follow a coherent logic, moving from the extent of technology use to the ways in which technology and AI are integrated into STEM teaching, then to the gap between activity design and learning-process management, and finally to implications for the development of teachers' digital competence.

2. RESEARCH METHODS

2.1. Research Design

The study adopted a quantitative approach using a questionnaire survey to collect information on the extent to which digital technology and artificial intelligence (AI) were applied in the design, organization, and assessment of STEM education activities at the lower secondary school level. The research design was descriptive, cross-sectional, and exploratory, with data collected at a single point in time and used to describe the extent of technology and AI use among the surveyed participants.

The survey content was developed based on the research objectives and an analytical framework addressing digital competence, digital pedagogical competence, and STEM education implementation. The questionnaire focused on specific manifestations of technology and AI use in teaching and learning, ranging from the use of digital learning resources and the design of STEM activities to the use of digital tools for assessment, monitoring, interaction, and student support, as well as teachers' perceptions of the effects of technology on STEM learning outcomes.

This design enabled the study to provide an initial description of digital technology and AI use across different stages of STEM education while also examining differences between technology use during the preparation and design stages and its use for monitoring, assessment, and student support during the learning process.

Because the study used a small sample and was exploratory in nature, the findings were primarily used to describe patterns within the surveyed group and were not intended for statistical inference or generalization to the broader population of lower secondary school teachers.

2.2. Participants and Sample

The participants were individuals involved in teaching and the implementation of STEM education at the lower secondary school level. The survey sample consisted of 19 respondents ($n = 19$), selected through convenience sampling within the practical scope of the study.

The sample size of $n = 19$ was intended to provide initial evidence regarding the application of digital technology and AI in STEM education. Given this sample size, the study explicitly limits interpretation to the descriptive and exploratory level. The percentages are used to represent the distribution of responses among the 19 participants and should not be interpreted as estimates representative of the population of teachers or lower secondary schools in the province.

Clearly defining the limitations of the sample helps ensure caution in interpreting the findings. The patterns identified in the survey are used as a basis for discussing teachers' digital competence and aspects that warrant further attention in the implementation of STEM education.

2.3. Survey Instrument

The data collection instrument was a questionnaire consisting of seven questions, focusing on manifestations of digital technology and AI use in STEM education at the lower secondary school level.

The seven survey areas were as follows:

- (1) *Ability to search for, select, and use digital learning resources:* examining the extent to which teachers use digital resources to support the preparation and organization of STEM activities.
- (2) *Application of technology and AI in STEM lesson-plan design:* examining the extent to which teachers use technology and AI when developing lesson plans and designing STEM activities.
- (3) *Digital tools and AI enhance the visualization, creativity, and effectiveness of STEM education:* examining teachers' perceptions of the contribution of technology and AI to visualization, creativity, and the effectiveness of STEM activities.

(4) *Use of digital tools to monitor, assess, and evaluate the learning process and STEM products*: examining the extent to which technology is used to monitor task implementation and assess STEM learning products.

(5) *Use of digital tools such as Forms, Quizizz, and Padlet for assessing learning progress and student competencies*: focusing on the use of specific digital platforms to collect feedback and assess students' progress and competencies.

(6) *Use of technology and AI platforms to monitor, interact with, and support students during STEM product development*: examining the extent to which technology and AI are used to maintain interaction, monitor progress, and support students while they complete learning tasks.

(7) *Digital technology and AI increase students' interest, active problem-solving, and the quality of STEM products*: examining teachers' perceptions of the perceived effects of digital technology and AI on student engagement, active problem-solving, and the quality of STEM products.

The seven questions were designed to reflect different aspects of technology and AI integration in STEM, ranging from resource use, design, and organization to monitoring, assessment, student support, and perceived effects on learners. Accordingly, the questions were treated as separate descriptive indicators and were not aggregated into a composite score representing overall "digital competence."

2.4. Four-Level Response Scale

The questions used a four-level response scale, with wording adapted to the content of each question.

For items assessing the frequency or level of implementation, the response categories were arranged from higher to lower levels, corresponding to:

Level 1: Frequently/Very good;

Level 2: Sometimes/Good;

Level 3: Rarely/Average;

Level 4: Never/Weak.

For items assessing the level of agreement, the response categories were:

Level 1: Strongly agree;

Level 2: Agree;

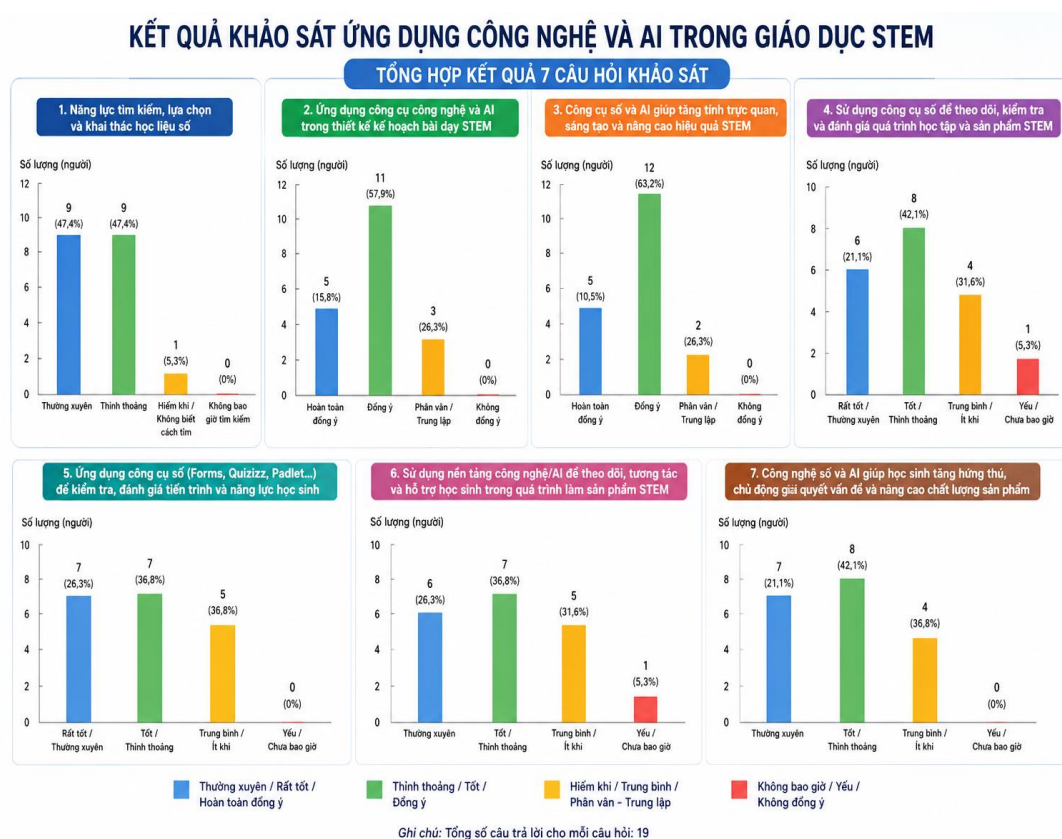
Level 3: Undecided/Neutral;

Level 4: Disagree.

The four-level response format enabled participants to indicate their level of use or agreement more explicitly while reducing the tendency to select a middle-point response. When appropriate, the response categories were grouped into two descriptive categories: the positive group, comprising Levels 1 and 2, and the less positive or limited group, comprising Levels 3 and 4.

However, combining the first two levels into a “positive” category was used solely to describe the distribution of responses and was not intended to establish that teachers had achieved a specific competency standard.

3. RESEARCH FINDINGS



3.1. Use of Digital Resources

The survey results show that searching for, selecting, and using digital learning resources is an aspect that teachers engage in relatively frequently in the implementation of STEM education. Among the 19 participants, 9 teachers (47.4%) reported using digital resources frequently, while another 9 teachers (47.4%) reported using them occasionally. Only 1 teacher (5.3%) selected the rarely category, and no participant selected never. Thus, 18 out of 19 teachers (94.8%) fell within the two more positive response categories.

These findings indicate that digital resources have become a relatively familiar component of STEM teaching preparation and implementation. Teachers may use online learning resources to search for information, images, videos, data, or reference materials to support the development of learning tasks. The widespread availability of search engines, learning-resource sharing platforms, and generative AI applications has also made access to teaching resources more convenient.

However, access to digital resources does not necessarily correspond to the ability to use such resources for specific pedagogical purposes. In STEM education, teachers need to determine the relevance of resources to learning objectives, the reliability of information, students' characteristics, and the requirements of real-world tasks. Particularly as AI becomes increasingly involved in generating and recommending content, teachers need to verify, cross-check, and adapt information before incorporating it into learning activities. Therefore, the high positive response rate for this indicator primarily reflects the level of digital resource use and is not sufficient to provide a comprehensive assessment of the quality of resource use or teachers' ability to evaluate digital resources.

3.2. STEM Design Supported by Technology and AI

Compared with the use of digital resources, indicators related to the integration of technology and AI into STEM activity design showed lower levels of positive responses. Regarding the application of technology and AI in designing STEM lesson plans, 3 teachers (15.8%) selected the highest positive response category, 11 teachers (57.9%) selected the moderate/adequate category, and 5 teachers (26.3%) were in the moderate/limited category. Thus, 14 out of 19 teachers (73.7%) fell within the two more positive response categories.

For the statement that digital tools and AI enhance the visualization, creativity, and effectiveness of STEM education, 2 teachers (10.5%) selected the highest category, 12 teachers (63.2%) selected the moderate/adequate category, and 5 teachers (26.3%) selected the moderate/limited category. The overall proportion of positive responses was also 73.7%. No teacher selected the disagree category.

These findings suggest that teachers recognize the value of technology and AI in STEM design, particularly in enriching learning resources, visualizing content, and supporting the development of learning tasks. However, approximately one-quarter of participants did not report positive levels on these two indicators. This suggests that the transition from using technology to support lessons toward redesigning learning activities based on the affordances of technology and AI is occurring at different levels.

In the STEM context, technology integration is meaningful when tools are selected appropriately for real-world problems, design processes, collaborative activities, and student products. Therefore, the challenge is not simply whether teachers know how to use a technological or AI tool, but also whether they can determine when to use it, which pedagogical problem it is intended to address, and how to use it to enhance students' cognitive engagement.

3.3. Digital Assessment Methods

The survey results regarding the use of digital tools to monitor, assess, and evaluate learning processes and STEM products indicate a lower level of positive responses than the use of digital resources. Four teachers (21.1%) selected the highest positive category, while 8 teachers (42.1%) selected the moderate/adequate category. Thus, 12 out of 19 teachers (63.2%) fell within the two more positive response categories. Meanwhile, 6 teachers (31.6%) were in the moderate/limited category and 1 teacher (5.3%) selected the below-adequate category.

These findings indicate that digital assessment methods are used by a substantial proportion of teachers in STEM implementation, but the level of application is not uniform. Digital technology can help teachers collect feedback more efficiently, store learning results, and monitor students' progress in completing tasks. Tools such as online forms, assessment platforms, and interactive applications can create additional opportunities for formative assessment rather than focusing exclusively on final outcomes.

However, the use of digital assessment tools generates pedagogical value only when the information obtained is used to adjust teaching and learning activities. In STEM education, assessment should address not only knowledge but also problem-solving processes, the ability to apply knowledge, collaboration, design, and product improvement. Therefore, the 63.2% positive response rate can be regarded as an initial indication of digital assessment use, while also suggesting considerable room for strengthening teachers' capacity to design and use digital assessment in a competency-oriented manner.

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However, access to digital resources does not necessarily correspond to the ability to use such resources for specific pedagogical purposes. In STEM education, teachers need to determine the relevance of resources to learning objectives, the reliability of information, students' characteristics, and the requirements of real-world tasks. Particularly as AI becomes increasingly involved in generating and recommending content, teachers need to verify, cross-check, and adapt information before incorporating it into learning activities. Therefore, the high positive response rate for this indicator primarily reflects the level of digital resource use and is not sufficient to provide a comprehensive assessment of the quality of resource use or teachers' ability to evaluate digital resources.

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4.4. Digital Monitoring and Student Support

The survey results regarding the use of digital tools and AI to monitor, interact with, and support students during the development of STEM products show a similar pattern. Five teachers (26.3%) selected the highest positive response category, 7 teachers (36.8%) selected the moderate/adequate category, 6 teachers (31.6%) were in the moderate/limited category,

and 1 teacher (5.3%) selected the below-adequate category. Overall, 12 out of 19 teachers (63.2%) selected the two more positive response categories.

These findings indicate that digital technology is used not only to provide learning resources but has also begun to be used for monitoring and interacting with students. This represents an important step in the development of teachers' digital competence, as teachers need to use information from the learning process to identify difficulties, provide feedback, and support students in completing learning tasks.

However, the remaining 36.9% of respondents in the moderate/limited and below-adequate categories indicates that the use of technology for monitoring the learning process and personalizing support remains an area requiring attention. In STEM activities, students may encounter different challenges at different stages, including problem identification, information searching, solution development, experimentation, adjustment, and product refinement. Therefore, teachers' digital competence involves not only the ability to use digital platforms but also the ability to interpret learning-related information and translate it into appropriate pedagogical decisions.

4.5. From Technology Use to Pedagogical Integration: An Emerging Gap

When the survey findings are considered together, a notable pattern can be observed in the level of technology and AI integration in STEM implementation. The highest proportion of positive responses was found for the use of digital resources (94.8%). By comparison, indicators related to technology- and AI-supported STEM design reached 73.7%, while indicators concerning assessment, monitoring, and student support each reached 63.2%.

This difference should be interpreted cautiously because the study involved only 19 participants and relied on self-reported data. Nevertheless, at the descriptive level, the findings suggest a notable transition: teachers appear to experience greater ease in accessing and using technology, whereas the integration of technology into more complex pedagogical decisions, such as monitoring progress, providing feedback, assessing learning, and providing individualized support, appears to be more limited.

This process can be conceptualized as a sequence: Digital Resource Use → STEM Activity Design → Organization and Interaction → Progress Monitoring → Feedback and Support → Assessment and Improvement.

At the initial stage, technology primarily functions as a means for teachers to search for and provide learning resources. At the next stage, technology and AI begin to contribute to the design of learning activities. At a deeper level of integration, digital data are used to help

teachers understand individual students' learning processes and make appropriate adjustments.

Accordingly, the findings suggest three levels of development in the integration of technology and AI into STEM education. The first level is utilization, focusing on searching for, selecting, and using digital resources. The second level is integration, in which technology and AI are incorporated into the design, organization, and assessment of STEM activities. The third level is management and personalization, in which digital data are used to monitor progress, provide feedback, support students, and adjust learning activities.

From this perspective, the development of teachers' digital competence should not focus solely on adding more technical skills for operating digital tools. More importantly, teachers need to understand the pedagogical value of technology, select tools according to learning objectives, and use technology-generated data to inform professional decisions. This requirement is particularly important for AI, as teachers continue to play a central role in verifying information, designing learning tasks, ensuring content appropriateness, and maintaining students' active engagement in learning.

Thus, the survey findings do not allow the study to claim a representative competency gap among lower secondary school teachers in general. However, they provide initial empirical evidence of a gap between "technology use" and "technology integration into pedagogy" in the context of STEM implementation. This finding may provide a basis for future studies to expand the sample and combine survey data with classroom observations, teacher interviews, lesson-plan analysis, and other sources of evidence and STEM products to further examine this emerging pattern.

5. DISCUSSION

5.1. Technology Is More Widely Used During the Preparation and Design Stages

The findings show that digital technology is used relatively readily by teachers in activities related to searching for and selecting learning resources and preparing STEM lesson designs. The highest proportion of positive responses was associated with the use of digital resources, while indicators related to technology- and AI-supported STEM design also showed relatively positive levels. This suggests that technology has gradually become part of the instructional preparation process rather than being used solely as a means of presenting information or delivering content.

One possible explanation is that current digital tools are relatively accessible and can directly support routine teacher tasks, such as searching for information, developing instructional

materials, generating images, designing questions, or developing ideas for STEM tasks. In particular, generative AI can reduce the time required for certain preparation activities and expand the range of options that teachers can consider when designing learning activities.

However, frequent use of technology during the preparation stage does not necessarily mean that technology has been deeply integrated throughout the pedagogical process. A teacher may be proficient in using multiple tools to prepare lessons while still experiencing difficulties in using digital data to monitor learning processes, provide feedback, or adapt activities to individual students' needs. Therefore, the findings suggest the need to distinguish between technology use competence and the competence to integrate technology into pedagogical design.

In STEM education, this distinction is particularly important because learning activities typically follow a sequence involving problem identification, inquiry, design, experimentation, adjustment, and product refinement. Technology has greater pedagogical value when it is used throughout this sequence to support students in solving problems rather than being concentrated primarily on the teacher's preparation of instructional content.

5.2. Greater Challenges When Moving Toward Learning Process Management

An important finding of the study is that the proportion of positive responses tends to decrease as technology use shifts from resource use and design toward assessment, monitoring, and student support. This does not necessarily constitute a "competency gap" in an absolute sense, but it indicates differences in the complexity of technology-supported pedagogical tasks.

During the preparation stage, teachers primarily select and use readily available tools. In contrast, managing the learning process requires teachers to perform multiple tasks simultaneously: collecting information about students' learning progress, interpreting data, identifying difficulties, providing feedback, and adjusting learning activities. These tasks require the integration of technological knowledge, subject-matter knowledge, and pedagogical competence.

In STEM education, this requirement is even more complex because learning outcomes are not reflected solely in a final test but also emerge through students' processes of identifying problems, developing ideas, collaborating, experimenting, and improving products. Therefore, digital data become meaningful only when teachers are able to transform such data into information that supports pedagogical decision-making.

The survey findings therefore suggest that developing teachers' digital competence should not stop at training them to use individual platforms or software applications. Greater

emphasis should be placed on using digital data to manage the learning process, including monitoring progress, identifying difficulties, providing timely feedback, and adapting learning tasks. This may be one of the areas that warrants greater attention in teacher professional development programs for STEM education.

5.3. AI Expands Design Possibilities but Requires Verification and Ethical Considerations

The findings indicate that AI is perceived as a tool with the potential to support the design of STEM activities, enhance visualization, and expand teachers' capacity to develop instructional materials. AI can assist teachers in generating ideas for learning tasks, developing scenarios, proposing questions, creating different types of instructional materials, or adapting content to specific lesson requirements.

However, AI's ability to generate content rapidly also creates new requirements for teachers' professional roles. AI-generated content may be inaccurate, lack contextual relevance, or be inappropriate for students' learning levels. Therefore, teachers cannot treat AI-generated outputs as inherently reliable sources of information. Verification, selection, adaptation, and responsibility for the final content should remain with the human user.

In STEM education, this requirement is particularly important because learning tasks are often connected to real-world problems and require data accuracy, appropriate solutions, and the ability to apply knowledge. If AI-generated content is used without verification, teachers may unintentionally introduce inaccurate information or inappropriate learning tasks into the learning process.

Beyond accuracy, the use of AI also raises issues related to ethics and professional responsibility, including protecting student data, ensuring transparency in AI use, avoiding excessive reliance on AI-generated content, and maintaining learners' active roles in the learning process. Therefore, teachers' AI competence should be understood as a component closely connected to professional competence and professional ethics rather than merely the ability to operate a new set of technological tools.

From this perspective, AI does not replace teachers' pedagogical roles but changes the requirements associated with those roles. Teachers increasingly need to act as designers, verifiers, facilitators, and pedagogical decision-makers, with AI serving as a supporting tool rather than a decision-making agent replacing the teacher.

5.4. Implications for the Development of Digital Pedagogical Competence

The findings suggest that developing digital pedagogical competence among lower secondary school teachers should adopt an integrated approach rather than focus solely on tool-use skills. Several directions may be considered.

First, professional development should strengthen teachers' ability to select technologies according to pedagogical objectives. Teachers need support in determining which tools are appropriate for each stage of the STEM process rather than using technology simply because a particular tool is new or widely used.

Second, greater emphasis should be placed on the capacity to assess and use digital data. Professional development programs should guide teachers not only in creating online assessments but also in interpreting results, identifying learning difficulties, and using the information obtained to adapt learning activities.

Third, responsible AI use should be developed as an essential component of teachers' competence. Professional development should include skills in formulating effective prompts, verifying information, recognizing the limitations of AI, protecting data, ensuring transparency in AI use, and maintaining teachers' professional decision-making authority.

Fourth, digital competence development should be connected to authentic STEM tasks. Rather than training teachers to use individual software applications in isolation, teachers could engage in lesson-design scenarios, STEM task development, product assessment, and learning-data analysis. This approach places technology within the actual pedagogical contexts in which teachers are expected to use it.

Finally, the findings suggest a need to shift the focus from the question "Do teachers use technology?" to the question "How do teachers use technology and AI to enhance the quality of learning activities?" This shift is important for the development of digital pedagogical competence because the ultimate goal is not to increase the number of tools being used but to strengthen teachers' capacity to design, organize, monitor, assess, and personalize learning processes in STEM education.

CONCLUSION

This study examined the application of digital technology and artificial intelligence (AI) in the implementation of STEM education at the lower secondary school level, focusing on the use of digital resources, STEM activity design, digital assessment, and the monitoring and support of students. Based on a survey of 19 teachers, the findings indicate that digital

technology has been used relatively widely, particularly for searching for and accessing resources to support teaching and learning.

However, the level of integration tends to decrease when technology is used for more complex pedagogical tasks. While 94.8% of participants selected the two positive response categories regarding the use of digital resources, the corresponding proportion for indicators of technology- and AI-supported STEM design was 73.7%, whereas the indicators related to assessment, monitoring, and student support were each at 63.2%. These findings suggest a descriptive gap between technology use and the integration of technology into the pedagogical process.

The study also indicates that AI has the potential to expand teachers' capacity to design instructional materials and STEM activities. However, the use of AI requires competencies in information verification, content selection, data protection, and responsible decision-making. Therefore, the development of teachers' digital competence should extend beyond training in tool-use skills toward the ability to select appropriate technologies, integrate technology with pedagogical approaches, utilize learning data, and use AI responsibly.

Although the findings cannot be generalized to lower secondary school teachers as a whole, the study provides exploratory evidence suggesting that the focus of teacher professional development is shifting from "technology use" toward "purposeful technology integration for pedagogical purposes." This direction requires further examination through studies with larger samples, multiple data sources, and more in-depth research designs.

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