

ENHANCING TEACHERS' DIGITAL COMPETENCE THROUGH A DIGITAL LEARNING RESOURCE ECOSYSTEM FOR THE “SUBSTANCES AND TRANSFORMATION OF SUBSTANCES” MODULE IN GRADE 9 NATURAL SCIENCE

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Abstract. In the present era of digitalization, digital competence has become a vital criterion for teachers. In particular, for the "Substances and transformation of substances" content, which is included in the Natural Science subject under the framework of 2018 General Education Program, there is much abstract information that needs to be taught. In this regard, the present research has created and implemented a unique digital learning ecosystem for the above content. This has been done with the aim of supporting the work of teachers during their teaching activities as much as possible. The research has involved the implementation of a one-group pretest-posttest pre-experimental design using 97 secondary school teachers across the country. There was a positive change in the fields of self-assessed digital competence, especially in the field of digital instruction organization and empowering learners.

Keywords: digital competence, digital pedagogy, teacher professional development, one-group pretest-posttest design, Grade 9 Natural Science.

1. Introduction

Digital competence is currently one of the decisive factors for national education. It is also a prerequisite for teachers to enhance educational quality. Therefore, teachers' digital competence has become a prominent topic for researchers to explore. Skantz-Åberg et al. (2022) identified seven main aspects of this competence, which fall broadly into technological and pedagogical competences. Currently, the digital competence is not only the ability to use the teaching tools but also consists of the problem-solving skills, ethics, and other social aspects. This requires the teachers to be proficient in using the technology as the tool for knowledge creation (Falloon, 2020; Martínez-Bravo et al., 2022).

The global tendency in this field and specifically in Vietnam is that the digital transformation in education receives great attention and support from the government. As it is noted in Decision No. 131/QĐ-TTg and Official Dispatch No.5835/BGDDT-KHCNTT, the education system's transition to the digital age is a pressing priority. For this reason, competence frameworks are now being created for the particular context. P.Q.Nguyen (2023) proposed the digital competence framework for teachers including three main domains, and Ha et al. (2025) proposed the framework including four main components.

While the previous researches have only managed to present generalized models or the overall assessment of teachers' digital competence, the literature is lacking in the development of discipline-specific digital competence models associated with certain content. Although models like DigCompEdu are comprehensive, they still lack a vital element that allows determining the level of subject-specific competence for certain subjects (Kotzebue et al., 2021; Lahn & Berntsen, 2023). The module “Substances and transformation of substances” in Grade 9 Natural Science

especially highlights the deficiency of such models associated with digital tools that allow visualization of complex concepts or simulating dangerous reactions that can hardly be performed by lower secondary school students. In Vietnam, Grade 9 Natural Science under the 2018 General Education Program poses many challenges for both teachers and students. Specifically, the “Substances and transformation of substances” module in grade 9 contains many abstract concepts and chemical reactions that are difficult for lower secondary school students to perform. Therefore, the shortage of a digital learning ecosystem is a massive challenge in organizing teaching for teachers and acquiring knowledge for students.

To fill this gap, this study proposes a specialized digital learning resource ecosystem to enhance teachers' digital competence through the grade 9 “Substances and transformation of substances” module. This ecosystem plays an important role in creating an interactive environment to help teachers proactively practice pedagogy. Above all, this study aims to: (1) design a digital learning resource ecosystem for the “Substances and transformation of substances” module in Grade 9 Natural Science; (2) conduct pedagogical experimentation to evaluate the feasibility and effectiveness of digital learning resources in enhancing teachers' digital competence. Therefore, this study focuses on addressing the following research questions:

(RQ1) What components does the digital competence framework for Natural Science teachers include?

(RQ2) How should the digital learning resource website be designed and structured so that teachers can effectively integrate it into teaching practices?

Theoretically, this study explores an alternative to fragmented technology workshops by modeling teacher professional development integrated directly into specific subject content. Practically, while acknowledging the limitations of self-reported data, this research provides descriptive evidence on how a digital learning resource ecosystem can enhance teachers' perceived confidence in leveraging visual resources. This approach aims to support the methodological innovation requirements of Vietnam's 2018 General Education Program by evaluating these self-reported competence gains, thereby establishing a foundational step for future investigations into authentic, observable classroom impacts.

2. Literature review

2.1. Digital competence

Digital competence is considered one of the eight key competencies for lifelong learning. (Sala et al., 2020). Terms such as “digital competence”, “digital literacy” or “digital skills” have equivalent meanings in different contexts (Audrin & Audrin, 2022). Besides, digital competence is understood as the ability to coordinate knowledge, skills, and attitudes when using digital resources to plan, implement, and evaluate teaching to plan, implement in practice, and evaluate the teaching process (From, 2017). It extends beyond mere technical operations to encompass the capacity for critical thinking, information evaluation, and knowledge across diverse digital platforms (Park et al., 2021). Tran & Nguyen (2022) suggest that teachers' digital competence is not only demonstrated through proficiency in using underlying technologies but also through a proactive, positive, and responsible attitude during the use of a digital learning resource ecosystem.

Digital Competence is broadly defined as the ability to search, evaluate, utilize, share, and create content through digital technologies and the Internet (Reddy et al., 2022). More specifically, digital competence in teaching – often referred to as digital pedagogical competence – is demonstrated through the integration of technology across the instructional workflow, ranging from digitizing educational content, designing lesson plans, and managing online learning environments via Learning Management Systems (LMS) using modern pedagogical methods, to employing assessment software to evaluate learner performance (T. G. Nguyen, 2022). However,

teachers may possess technical knowledge of digital tools without effectively integrating them into their authentic pedagogical practices, and demographic factors such as age or gender have been shown to influence variations in digital competence levels (Guillén-Gámez et al., 2021).

2.2. Digital competence framework for teachers

While global models like DigCompEdu provide robust foundations for general digital skills, they often lack discipline-specific operationalization. Therefore, this study adapts the digital competence framework issued by the Vietnamese Ministry of Education and Training (MOET, 2026). To ensure consistency with national evaluation standards, this study retained the five core domains, but streamlined the performance indicators into 14 focal items to strictly isolate pedagogical competencies related to the Grade 9 Natural Science curriculum, while deliberately excluding broad administrative information technology tasks. These 14 items are evaluated across three behavioral proficiency levels: Basic, Proficient, and Advanced.

Specifically, the proposed framework encompasses five core domains:

(1) Organizing Instruction in a Digital Environment (OIDE), which covers practices ranging from the use of basic 3D models to the development of data-informed learning pathways; (2) Assessment (AST), progressing from the application of simple quizzes to the use of learning analytics; (3) Empowering Learners (EML), moving from the integration of visual elements toward the creation of problem-based learning environments (PBL); (4) Digital Skills (DS), ranging from the identification of multimedia resources to the use of AI in independently developing instructional materials; and (5) Professional Development (PD), extending from participation in professional communities to the management of open repositories for collaborative resource development. This framework enables an objective evaluation of the effectiveness of pedagogical experimentation tied to teaching content by translating generic competencies into specific instructional tasks. Because of the limitation of space, the complete behavioral rubric is provided via the supplementary QR code (Figure 1).



Figure 1. QR code for digital competency framework

3. Methodology

3.1. Research design

This quantitative study adopted a one-group pretest-post test pre-experimental design to investigate changes in teachers' digital competence following the use of a customized digital learning resource ecosystem for the Grade 9 Natural Science module "Substances and transformation of substances". As the study lacks a control group, it makes no causal statements; however, the analysis is focused on observed correlations and changes in teachers' digital pedagogical competencies.

Implementation of the intervention was based on integration of the digital ecosystem into the practice. To maintain implementation fidelity, the 5-to-7-week intervention was conducted in several provinces and cities, including Hanoi, Ninh Binh, Phu Tho, and Hung Yen. First, a 4-hour-long online workshop conducted by educational technology researchers was held. This workshop provided direct instruction and demonstration on how to operate the platform and incorporate digital tools (e.g., virtual simulations) into standard lesson plans. Second, during the whole intervention, teachers were required to integrate the provided resources into at least one lesson of Natural Science each week. To assess implementation without broadening the quantitative research scope, the usage of resources was monitored using simple weekly checklists. The dependent variable of the study was teachers' self-reported digital competence in the five domains.

3.2. Participants

The final sample consisted of 97 secondary school teachers (N = 97) that were teaching the Grade 9 Natural Science program. The participants were selected using convenience sampling

from local educational circles in the abovementioned provinces of Vietnam. The specific target group was selected since those teachers experience direct instructional challenges with teaching abstract chemical concepts and need digital visualization tools desperately. Participation was entirely voluntary, and all information gathered was kept anonymous and strictly confidential. Even though convenience sampling made it easy to gather data from the relevant participants, the researcher understands that such a non-probability sampling method does not provide generalizability of the results to the whole population of teachers in Vietnam.

3.3. Data collection instruments and data analysis

The data were collected using a teacher self-assessment survey on digital competence, digitized using Google Forms. The survey included the following two sections:

Section 1 (Demographic information): Collects information about gender, region where the participant works, their years of teaching experience, and qualification level.

Section 2 (Digital competence scale): The scale operationalizes the framework developed by MOET in 14 subject-specific pedagogical tasks in the Grade 9 Natural Science course. Every item is measured on a 3-point ordinal scale (1 = Basic, 2 = Proficient, 3 = Advanced). For instance, "using visual elements (science comics, 3D images)" is the operationalization of the Level 1 strategy used to capture students' attention at the Empowering Learners level. "Using platforms which allow for using AI and virtual reality" is the operationalization of the Level 3 ability of designing new science simulations at the Digital Skills level. Similarly, "attending professional forums (e.g., Padlet)" can be seen as the operationalization of Level 1 behavior of accessing shared resources at the Professional Development level. Such criteria guarantee the consistency of evaluation; however, the limited range of responses might lead to ceiling effects. In addition, the use of self-reported perceived competence makes the data vulnerable to common method variance (CMV) problems, such as social desirability bias.

Procedure for Data Collection and Statistical Analysis: The questionnaire was administered during two separate times: pretest at baseline before having access to the website and posttest after pedagogical intervention to measure change in perceived competence. Data analysis was performed using IBM SPSS Statistics (Version 28.0). Data analysis involved: (1) descriptive statistics for demographic characteristics; (2) evaluation of reliability and validity of scales through Cronbach's Alpha, Spearman-Brown coefficient, and Exploratory Factor Analysis (EFA) through PCA with Varimax rotation; (3) paired-samples t-tests combined with Cohen's d_z to measure pretest-posttest changes; and (4) Welch's t-test, one-way ANOVA, and Kruskal-Wallis test to analyze subgroup differences in terms of demographic variables.

4. Results and discussion

4.1. Designing a digital learning resource ecosystem to enhance teachers' digital competence in grade 9 Natural Science ("substances and transformation of substances")

4.1.1. Principles and criteria for ecosystem design

Scientific rigor and alignment with curriculum: Digital learning content must be accurate, rigorous, up-to-date, logically structured and systematic; it must be based on a solid scientific foundation in consultation with experts and the literature. In order to facilitate digital pedagogy in a discipline-specific context, all the learning resources are scientifically accurate and are aligned with the 2018 General Education Curriculum for Natural Science of Vietnam and can be integrated into standard pedagogical lesson plans (e.g., according to Official Dispatch No. 5512/BG-DDT-GDTrH).

Interactivity and co-creation of resources: Platform design highlights usability, user-friendly interface, cross-device support, and bi-directional feedback process in which teachers act

as learners and creators of learning resources. It reflects the Advanced proficiency level of the MOET framework of digital competence, allowing teachers to actively co-create educational resources rather than consuming them passively.

Pedagogic appropriateness and practical significance: Materials related to the ecosystem must correspond to the key objective of improving the teachers' digital literacy and facilitating the teaching of Grade 9 Natural Science. They must be visually appealing and include open materials and promotion of self-guided learning and inquiry in pedagogy. From a functional perspective, the selected digital technology is intended to solve specific pedagogical problems, such as visualization of abstract microscopic processes and the ability to conduct dangerous chemical experiments safely, thereby filling the gap between general IT education and instruction.

Aesthetics and cognitive economy: The interface must be easy to understand, utilizing well-coordinated color combinations and a consistent design that focuses on visualizations (such as interactive diagrams and high-quality models), rather than being heavy with text.

4.1.2. Design Process

To ensure methodological rigor and provide a theoretical foundation for the ecosystem components, the development process was framed using the established ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) (Adeoye et al., 2024). Following this framework, the development process was organized into three phases:

Phase 1: Content preparation and system architecture (analysis and design): Relevant literature on digital resource design and Vietnam's 2018 General Education Curriculum to develop digital learning resources specifically tailored for the "Substances and transformation of substances" module in Grade 9 Natural Science was reviewed.

Phase 2: Platform construction and competence alignment (development): Based on the proposed structure, the digital ecosystem platform was developed to integrate the selected multimedia resources. The platform was organized as both a learning resource repository and a collaborative community to support the key domains of the MOET digital competence framework for teachers.



Figure 2. QR code for website access

Phase 3: Pedagogical piloting and interactive refinement (implementation, and evaluation): Based on proposed design, the digital ecosystem platform was designed to integrate the selected multimedia resources. The platform was divided into two sections: repository of learning resources and a collaborative space, which helped to address domains of the MOET teacher digital competence framework.

4.1.3. Ecosystem design specifications

The platform served as a digital repository of resources as well as a tool for instruction. Its organization provided teachers with access to a range of materials, such as 3D molecular models and gamified worksheets for the topic "Substances and transformation of substances" in Grade 9 Natural Science. To support teaching practice and professional development, they were aligned with the relevant pedagogical functions and domains of the MOET teacher digital competence framework (Table 1). However, this alignment was not reviewed by an expert panel, which should be acknowledged as a limitation of the study.

Table 1. Pedagogical functions and targeted digital competence domains of the digital learning resource ecosystem

Ecosystem feature	Primary instructional function	Targeted digital competence domains and indicator
3D models	Visualizing spatial molecular structures and abstract microscopic concepts.	- Organizing instruction in a digital environment (OIDE1) / digital skills (DS1)

Virtual experiments	Simulating complex or hazardous chemical transformations to ensure safety in instructional practice.	- Organizing instruction in a digital environment (OIDE2) - Empowering learners (EML2)
Interactiveworksheets	Conducting regular formative assessments with automated scoring and instant feedback.	- Assessment (AST1) - Organizing Instruction in a digital environment (OIDE)
Educational games	Integrating interactive gamification to facilitate engaging formative assessments.	- Assessment (AST2) - Empowering learners (EML1)
Science comics	Leveraging relatable storytelling to convey scientific knowledge and enhance intrinsic student motivation.	Empowering learners (EML1)
Mind maps	Systematizing core knowledge and illustrating logical relationships through digital content creation.	- Organizing instruction in a digital environment (OIDE1) - Digital skills (DS2)
Ai assistant	Facilitating idea generation for lesson plan design and drafting assessment questions.	- Digital skills (DS3), - Assessment (AST3),
Community space (padlet & google forms)	Facilitating the sharing of pedagogical materials, peer discussions, and collaborative resource co-creation.	Professional development (PD1 & PD3)

4.2. Results

4.2.1. Demographic profile of participants

Among the 97 participating teachers, females accounted for 78.4% of the sample. Participants were drawn from urban (48.5%), rural (38.1%), and mountainous areas (13.4%). In terms of teaching experience, teachers with 1-5 years of experience formed the largest group (57.7%), followed by those with more than 15 years (23.7%), 10-15 years (12.4%), and 5-10 years (6.2%). Overall, it may be concluded that the sample was appropriate for the study, as the sample was sufficiently diverse to support subgroup comparisons.

4.2.2. Construct validity and exploratory factor analysis

Before examining the effects of the intervention, an Exploratory Factor Analysis was performed using the Principal Component with Varimax rotation method. The extracted factors explained 57.73% of the variance in the pre-test and 59.27% in the post-test. After setting the loading criterion at 0.50, the majority of items were found to have satisfactory factor loadings, thus supporting the validity of the instrument for the Grade 9 Natural Science educational context.

Table 2. Reliability by construct

Construct	Items	Pre-test α	Post-test α	Pre-test corrected item-total correlation range	Post-test corrected item-total correlation range	Pre-test Spearman–Brown	Post-test Spearman–Brown
OIDE	4	0.820	0.756	0.520–0.698	0.489–0.614	—	—
AST	3	0.587	0.656	0.415–0.415	0.490–0.490	0.587	0.657
EML	2	0.542	0.625	0.376–0.376	0.463–0.463	0.547	0.633
DS	3	0.610	0.709	0.339–0.515	0.459–0.644	—	—
PD	3	0.589	0.631	0.287–0.554	0.439–0.464	—	—

Note: OIDE = Organizing Instruction in a Digital Environment; AST = Assessment; EML = Empowering Learners; DS = Digital Skills; PD = Professional Development.

Because AST and EML each consist of only two items, their alpha coefficients were inevitably modest; this is a known statistical limitation of short scales rather than a substantive

weakness. OIDE's coefficient, in comparison, was markedly stronger. Taken together, the pre-test ($\alpha = 0.879$) and post-test ($\alpha = 0.890$) values for the overall scale fall within an acceptable range. Post-test reliability improved, but we suspect part of that gain came from familiarity with the survey rather than a genuine improvement in digital competence.

Table 3. Pre-test and post-test comparison by construct (paired-samples t-test)

Construct	Pre-test M $\pm$ SD	Post-test M $\pm$ SD	Mean difference	95% CI of difference	t	p	Effect size (Cohen's dz)
Overall	1.578 $\pm$ 0.345	1.979 $\pm$ 0.341	0.401	[0.361, 0.441]	19.906	< .001	2.021
OIDE	1.549 $\pm$ 0.459	2.031 $\pm$ 0.401	0.482	[0.417, 0.547]	14.777	< .001	1.500
AST	1.505 $\pm$ 0.448	1.881 $\pm$ 0.419	0.376	[0.301, 0.452]	9.877	< .001	1.003
EML	1.572 $\pm$ 0.489	2.031 $\pm$ 0.499	0.459	[0.378, 0.539]	11.305	< .001	1.148
DS	1.646 $\pm$ 0.399	1.973 $\pm$ 0.435	0.326	[0.259, 0.394]	9.549	< .001	0.970
PD	1.601 $\pm$ 0.399	1.945 $\pm$ 0.387	0.344	[0.282, 0.405]	11.060	< .001	1.123

Note: OIDE = Organizing Instruction in a Digital Environment; AST = Assessment; EML = Empowering Learners; DS = Digital Skills; PD = Professional Development.

Table 3 presents the differences in perceived digital competence scores before and after the intervention. At the overall level, the mean score increased from 1.578 to 1.979 ($p < .001$, Cohen's $dz = 2.021$). Descriptive score increases were observed across all five subscales, with the highest mean differences recorded in OIDE and EML. Given the one-group pre-experimental design, these changes represent observed developmental shifts rather than definitive causal effects.

Table 4. Exploratory subgroup differences in overall gain scores

Grouping variable	Subgroup means (M $\pm$ SD)	Statistical test	p	Effect size / note
Gender	Male: 0.313 $\pm$ 0.127; Female: 0.425 $\pm$ 0.208	Welch's t = -3.064	.003	Cohen's d = 0.578
Area	Mountainous: 0.291 $\pm$ 0.118; Rural: 0.444 $\pm$ 0.206; Urban: 0.397 $\pm$ 0.200	ANOVA F = 2.997; Kruskal–Wallis H = 7.058	.055 (ANOVA); .029 (K-W)	$\eta^2 = 0.060$
Teaching experience	1–5 years: 0.364 $\pm$ 0.191; 5–10 years: 0.476 $\pm$ 0.117; 10–15 years: 0.601 $\pm$ 0.225; >15 years: 0.366 $\pm$ 0.154	ANOVA F = 6.111; Kruskal–Wallis H = 14.546	< .001 (ANOVA); .002 (K-W)	$\eta^2 = 0.165$

4.3. Discussion

Exploratory analyses (Table 4) indicate that female teachers ($M = 0.425$) showed a significantly larger mean gain than male teachers. Teachers in rural areas demonstrated the highest gain compared to urban and mountainous regions (Kruskal–Wallis $H = 7.058$, $p = .029$). The most pronounced subgroup variance was associated with teaching experience, where mid-career teachers (10 - 15 years) exhibited the most substantial improvement (ANOVA $F = 6.111$, $p < .001$, $\eta^2 = 0.165$).

The current study explored the integration of a discipline-specific digital learning resource ecosystem and its relationship with the perceived digital competence of Grade 9 Natural Science teachers. The observed data indicate a statistically significant positive trend in teachers' self-reported competence scores following the utilization of this specialized platform.

OIDE and EML registered the most substantial descriptive gains. Recent scholarship contends that digital competence takes root more successfully in a discipline-specific setting (Caviglia et al., 2026; Sailer et al., 2021). Dincer (2024) notes that generic ICT training programs

often fail to connect technical skill with classroom practice. The intervention, in contrast, used domain-specific tools, such as 3D molecular models and virtual chemical experiments, that targeted instructional challenges in the “Substances and transformation of substances” module.

Teachers were able to safely simulate hazardous reactions and visualize microscopic phenomena through the platform, making its practical value apparent almost immediately. This appears to have strengthened teacher confidence in designing lessons that are more student-centered and digitally integrated. The pattern aligns conceptually with Technological Pedagogical Content Knowledge (TPACK), a framework built on the intersection of technology and content knowledge (Aslan et al., 2025). Digital lesson plans were not analyzed qualitatively, and TPACK constructs were not formally assessed. This relationship remains speculative, pointing to a direction for future empirical work.

Subgroup analyses revealed unexpected patterns. Mid-career teachers, with 10 to 15 years of experience, reported the most pronounced gains in perceived competence. Early-career “digital native” teachers were expected to adapt most readily; that assumption did not hold. These mid-career teachers may possess a consolidated foundation in Pedagogical Content Knowledge (PCK). Novice teachers are often still managing classroom logistics and curriculum familiarization (Scherer et al., 2021), leaving mid-career teachers more cognitive capacity to focus on integrating new digital tools.

Furthermore, rural teachers showed significantly greater improvement than urban teachers. Rural settings may have started from a more acute baseline scarcity of interactive resources, meaning a comprehensive, open-access digital ecosystem yielded a larger perceived marginal benefit there. Recent literature shows targeted digital interventions in rural contexts tend to produce accelerated competency growth by overcoming longstanding barriers to technical resource access (Mwansa et al., 2025; Pan et al., 2025).

Limitations and future directions: While the results offer a promising foundation for subject-specific professional development practices, these should be interpreted within the confines of methodological limitations.

First, the pre-experimental, one-group pretest-posttest design is inconclusive in terms of causal inferences about the efficacy of the ecosystem intervention. History (participant maturation, concurrent professional development activities) and testing threats could account for the observed score increments.

Second, survey-based, self-reported competency data are susceptible to common method variance (CMV) and social desirability biases, thus reflecting participants’ more positive self-appraisal right after the intervention.

Third, utilizing a three-level behavioral ordinal Likert scale constrained the variance and likely resulted in ceiling effects, thereby inflating Cohen’s $d_z = 2.021$ (an unusually large effect size for this study). Specifically, paired-samples analyses employing such a restricted interval have a much smaller standard deviation of the difference scores than would be expected if scores were truly normally distributed, thus inflating the calculated effect size. While the intervention did yield positive descriptive changes in the measured variables, these were likely overestimated due to the statistical properties of the used scale.

Fourth, it must be stressed that the adapted proficiency descriptors were strongly focused on the specific functions of the digital ecosystem under review. While this choice was justified in terms of maximizing the fit of the intervention to the measured target variables, the measurement model prioritized the assessment of the pedagogical applications of the particular platform over general digital competence.

Finally, as mentioned in the methodology, no formal expert-panel validation of the item-to-competence mapping was employed, which could be considered a significant limitation.

Future studies should employ more sophisticated quasi-experimental or randomized designs involving control groups. Simultaneously, scholars should aim to triangulate self-reported competency levels with alternative, objective measures: standardized classroom observation rubrics, qualitative analyses of lesson plans (e.g., adherence to the MOET Official Dispatch 5512 recommendations), and student learning outcomes to assess the long-term efficacy of the subject-specific digital ecosystem interventions.

5. Conclusions

This study examined a discipline-specific digital learning resource ecosystem developed for the "Substances and transformation of substances" module in Grade 9 Natural Science. Teachers' self-assessed digital competence increased significantly after engaging with the platform ($t = 19.906$; $p < 0.001$). The strongest perceived gains were found in Organizing Instruction in a Digital Environment (OIDE) and Empowering Learners (EML). These shifts, however, only point to a change in teachers' self-perceived readiness to integrate digital pedagogy; no student outcome data were collected, so any claim about the platform's actual effect on student-centered scientific inquiry remains speculative. The statistical gains should also be read cautiously in causal terms, since the one-group pretest-posttest design leaves several potential confounding factors unaccounted for.

Exploratory analyses further showed that female teachers, mid-career educators (10 to 15 years of experience), and teachers in rural areas reported the largest score increases. Taken together with these methodological caveats, the findings still point to real value in embedding digital professional development directly within subject content. A domain-specific approach of this kind may help teachers see more clearly how the technology applies in practice, which in turn could support ongoing, self-directed professional growth.

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REFERENCES

- Adeoye, M. A., Wirawan, K. A. S. I., Pradnyani, M. S. S., & Septiarini, N. I. (2024). Revolutionizing education: Unleashing the power of the ADDIE model for effective teaching and learning. *JPI (Jurnal Pendidikan Indonesia)*, 13(1), 202–209. <https://doi.org/10.23887/jpiundiksha.v13i1.68624>
- Aslan, S., Alanoğlu, M., & Karabatak, S. (2025). Enhancing 21st-century teaching competencies: The key role of digital literacy in connecting pre-service teachers' TPACK. *Information Development*. <https://doi.org/10.1177/02666669251315841>
- Audrin, C., & Audrin, B. (2022). Key factors in digital literacy in learning and education: a systematic literature review using text mining. *Education and Information Technologies*, 27(6), 7395–7419. <https://doi.org/10.1007/s10639-021-10832-5>
- Caviglia, F., Boie, M. A. K., Dalsgaard, C., & Pedersen, A. Y. (2026). Bringing digital competence to the disciplines. *Education Inquiry*, 17(1), 34–62.

<https://doi.org/10.1080/20004508.2024.2318842>

- Dinçer, S. (2024). Bridging the gap in technology integration in education: An examination of science teachers' competencies and needs. *Journal of Turkish Science Education*, 21(4), 620–634. <https://doi.org/10.36681/tused.2024.033>
- Falloon (2020): From digital literacy to digital competence: the teacher digital competency (TDC) framework, *Educational Technology Research and Development*, 68, 2449–2472, DOI: 10.1007/s11423-020-09767-4.
- From, J. (2017). Pedagogical digital competence-between values, knowledge and skills. *Higher Education Studies*, 7(2), 43. <https://doi.org/10.5539/hes.v7n2p43>
- Guillén-Gámez, F. D., Mayorga-Fernández, M. J., Bravo-Agapito, J., & Escribano-Ortiz, D. (2021). Analysis of teachers' pedagogical digital competence: Identification of factors predicting their acquisition. *Technology, Knowledge and Learning*, 26(3), 481–498. <https://doi.org/10.1007/s10758-019-09432-7>
- Ha, V. D., Le, T. T. H., Nghiem, T. T., Ho, T. Q., Le, M. C., & Ly, T. T. H. (2025). Phát triển năng lực số của giáo viên phổ thông tại Việt Nam [Developing digital competence of general education teachers in Vietnam]. *Vietnam Journal of Education*, 25(4), 1–6 (in Vietnamese). <https://tcgd.tapchigiaoduc.edu.vn/index.php/tapchi/article/view/2965>
- Kotzebue, L. von, Meier, M., Finger, A., Kremser, E., Huwer, J., Thoms, L.-J., Becker, S., Bruckermann, T., & Thyssen, C. (2021). The framework DiKoLAN (Digital Competencies for Teaching in Science Education) as basis for the self-assessment tool DiKoLAN-Grid. *Education Sciences*, 11(12), 775. <https://doi.org/10.3390/educsci11120775>
- Lahn, L. C., & Berntsen, S. K. (2023). Frameworking vocational teachers' digital competences. *Nordic Journal of Comparative and International Education (NJCIE)*, 7(2). <https://doi.org/10.7577/njcie.5322>
- Martínez-Bravo, M. C., Sádaba Chalezquer, C., & Serrano-Puche, J. (2022). Dimensions of digital literacy in the 21st century competency frameworks. *Sustainability*, 14(3), 1867. <https://doi.org/10.3390/su14031867>
- Ministry of Education and Training. (2026). *Thông tư số 18/2026/TT-BGDĐT của Bộ Giáo dục và Đào tạo: Ban hành Khung năng lực số đối với giáo viên, cán bộ quản lý cơ sở giáo dục mầm non, phổ thông và giáo dục thường xuyên*. [Promulgating the Digital Competence Framework for teachers and administrators of preschools, general education, and continuing education institutions] (No. 18/2026/TT-BGDĐT dated 27/03/2026) (in Vietnamese). <https://vanban.chinhphu.vn/?pageid=27160&docid=217451>
- Mwansa, G., Ngandu, M. R., & Mkwambi, Z. (2025). Bridging the digital divide: exploring the challenges and solutions for digital exclusion in rural South Africa. *Discover Global Society*, 3(1), 54. <https://doi.org/10.1007/s44282-025-00189-2>
- Nguyen, P. Q. (2023). *Phát triển khung năng lực số cho giáo viên trong kỷ nguyên trí tuệ nhân tạo* [Developing digital competencies for teachers in the era of artificial intelligence]. *National Scientific Conference on Developing Teacher Competencies in the Context of Digital Transformation*, 254–261 (in Vietnamese).
- https://www.researchgate.net/publication/375773316_Phát_trien_khung_nang_luc_so_cho_giao_vien_trong_ky_nguyen_tri_tue_nhan_tao_Developing_digital_competencies_for_teachers_in_the_era_of_artificial_intelligence
- Nguyen, T. G. (2022). Đề xuất một số biện pháp phát triển “Năng lực số” cho đội ngũ giáo viên trong bối cảnh cách mạng công nghiệp 4.0 [Proposing some measures to develop "digital competence" for teachers in the context of the Industrial Revolution 4.0]. *Vietnam Journal of Education*, 22(19), 25–28 (in Vietnamese).

<https://tcgd.tapchigiaoduc.edu.vn/index.php/tapchi/article/view/540>

- Pan, H., Lin, Q., & Zhu, W. (2025). Overcoming the gap in technology integration in limited conditions in rural classrooms. *The Journal of Educational Research*, 118(5), 413–424. <https://doi.org/10.1080/00220671.2025.2490025>
- Park, H., Kim, H. S., & Park, H. W. (2021). A Scientometric study of digital literacy, ICT literacy, information literacy, and media literacy. *Journal of Data and Information Science*, 6(2), 116–138. <https://doi.org/10.2478/jdis-2021-0001>
- Reddy, P., Sharma, B., & Chaudhary, K. (2022). Digital literacy: a review in the South Pacific. *Journal of Computing in Higher Education*, 34(1), 83–108. <https://doi.org/10.1007/s12528-021-09280-4>
- Sailer, M., Schultz-Pernice, F., & Fischer, F. (2021). Contextual facilitators for learning activities involving technology in higher education: The Cb-model. *Computers in Human Behavior*, 121, 106794. <https://doi.org/10.1016/j.chb.2021.106794>
- Sala, A., Punie, Y., Garkov, V., & Cabrera, M. (2020). LifeComp the European framework for personal, social and learning to learn key competence. *JRC Science for Policy Report*. <https://doi.org/10.2760/302967>
- Scherer, R., Howard, S. K., Tondeur, J., & Siddiq, F. (2021). Profiling teachers' readiness for online teaching and learning in higher education: Who's ready? *Computers in Human Behavior*, 118, 106675. <https://doi.org/10.1016/j.chb.2020.106675>
- Skantz-Åberg, E., Lantz-Andersson, A., Lundin, M., & Williams, P. (2022). Teachers' professional digital competence: an overview of conceptualisations in the literature. *Cogent Education*, 9(1). <https://doi.org/10.1080/2331186X.2022.2063224>
- Tran, T. T. H., & Nguyen, K. Q. (2022). Năng lực kỹ thuật số của nhà giáo dục: Khái niệm liên quan và các bộ công cụ đánh giá [Educators' digital competence: related concepts and assessment toolkits]. *Vietnam Journal of Education*, 22(16), 24–28. <https://tcgd.tapchigiaoduc.edu.vn/index.php/tapchi/article/view/505>