Development of the Digital Teaching Competence of Elementary School Teachers Using the Delphi Technique

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Abstract

This study investigates the digital teaching competencies essential for elementary school teachers, utilizing the Delphi technique to gather expert insights. A panel of 11 educators participated in two rounds of surveys, leading to the identification of 33 key competency indicators. These indicators were categorized into five main dimensions: Teacher Digital Literacy, Digital Technology-Assisted Teaching Competence, Competence in Integrating Digital Technology into Subject Learning, Digital Teaching Strategies and Approaches, and Information Technology Skills. The findings revealed a consensus among experts regarding the importance of these competencies for effective digital instruction. Notably, indicators related to generative AI received low scores, reflecting limited teacher experience and perceived necessity in their teaching practices. The composition of the Delphi panel, primarily consisting of practitioners, influenced the practical nature of the recommendations, potentially overlooking broader innovative ideas. This research aims to construct a comprehensive framework for digital teaching competencies, addressing the growing significance of digital education in the post-pandemic era.

Keywords: Digital literacy, Delphi technique, Digital teaching, Information technology skills

1 Introduction

Since the outbreak of COVID-19 in 2019, the pandemic has precipitated profound transformations in global lifestyles. During the pandemic, educational institutions transitioned to online learning, leveraging information and communication technologies to facilitate digital education. In the post-pandemic era, digital pedagogical approaches have emerged as a prevailing trend. Educators are increasingly integrating digital tools and online learning platform resources into their instructional methods, which has not only enhanced educational effectiveness but also catalyzed innovative educational practices. Through these strategic interventions and concerted efforts, digital teaching modalities are poised to assume an increasingly pivotal role in future educational frameworks.

The rapid advancement of artificial intelligence technology has further catalyzed educational transformation. In 2022, OpenAI's ChatGPT (Chat Generative Pre-trained Transformer) demonstrated AI's formidable capabilities in linguistic tasks, profoundly impacting the academic landscape. Subsequently, AI tools like Google Bard and Microsoft Copilot emerged, further influencing education and daily life. These sophisticated AI platforms not only facilitate student learning but also assist educators in pedagogical management, thereby enhancing instructional effectiveness.

However, digital pedagogical transitions present significant challenges. Educators may lack comprehensive experience with digital tools and online learning platforms, resulting in technological unfamiliarity that necessitates substantial time investment to learn and adapt to evolving instructional methodologies. Teachers across different age groups and technological backgrounds may encounter "digital literacy barriers," struggling to seamlessly integrate and leverage emerging technologies, which consequently compromises classroom instructional quality.

Consequently, digital teaching competence is increasingly recognized as a critical component of effective education. The Digital Competence Framework for Educators delineates digital proficiencies across several pivotal domains, including professional engagement, digital resources, teaching and learning, assessment, empowering learners, and fostering learners' digital capabilities [1-2]. This comprehensive framework provides a foundational model for understanding the essential competencies educators need to integrate digital technologies into pedagogical practices effectively.

Research indicates that numerous educators frequently perceive inadequate digital competencies, potentially hindering their effective utilization of digital tools in classroom settings [3]. The systematic review underscored that many teachers lack confidence in their digital pedagogical skills, emphasizing the critical necessity for targeted professional development and training programs. Integrating digital technologies into instruction not only enhances student engagement but also demands educators recalibrate their teaching methodologies to meet the intricate requirements of digital learning environments [4].

Within this context, the Delphi technique has enabled comprehensive assessments of the requisite capabilities for digital instruction. Notably, research employing the Delphi

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DOI: https://doi.org/10.70003/160792642026112706011

method identified pivotal competencies for instructional delivery in one-to-one learning environments, highlighting the significance of expert consensus in delineating these skills [5]. This iterative process allows researchers to refine and validate the competencies essential for effective digital instruction, ensuring their relevance and applicability to contemporary educational practices.

Consequently, the digital era has comprehensively transformed education, fundamentally altering curriculum design, teaching methodologies, and educational policies through the integration of digital technologies. Teachers must not only acquire digital teaching competencies but also master the skills to effectively utilize AI tools in instruction. Government initiatives can enhance teachers' digital literacy through the implementation of digital teaching guidelines and various programs, ensuring the educational system effectively addresses the challenges of the digital age. Looking ahead, as technology continues to evolve, education will progress further toward digitalization and intelligent systems, providing a more robust foundation for cultivating digitally literate citizens.

1.1 Research Objectives

In the post-pandemic era, educators' utilization of digital tools and online learning platform resources for digital instruction has become a prevailing trend. Grounded in the aforementioned research motivation, this study explores the digital teaching competencies required by elementary school teachers, employing the Delphi technique to identify strategies for enhancing teachers' digital pedagogical capabilities. The specific research objectives are as follows:

1. Analyze the competencies elementary school teachers should possess for digital instruction.
2. Construct a comprehensive indicator framework for elementary school teachers' digital teaching competencies.

1.2 Research Questions

To comprehensively understand the competencies elementary school teachers should acquire for digital instruction, this study formulates the following three research questions based on the aforementioned research objectives:

1. What digital literacy skills should elementary school teachers possess?
2. What digital teaching competencies should elementary school teachers develop?
3. What information technology skills should elementary school teachers demonstrate?

1.3 Limitations of Research Subjects

According to the Ministry of Education's statistics, the total number of elementary school teachers in Taiwan is approximately 99,000. However, due to constraints in human resources, funding, and time, this study purposively sampled 11 experts from Kaohsiung City who are familiar with digital instruction in elementary schools. The sample includes practitioners such as academic directors, information technology coordinators, information secretaries, or teachers managing information-related teaching projects, forming the Delphi technique group for investigation. As other regions may have different circumstances due to local policies and urban-rural disparities, the research findings cannot be generalized to other areas across Taiwan.

1.4 Limitations of Research Methodology

This study employs the Delphi technique [6], where the selection of Delphi panel members significantly influences the establishment of indicator items. The experts selected for this research predominantly comprise practitioners with practical teaching experience, such as teachers and administrative teachers, with relatively fewer academic theorists. These experts' perspectives are largely constrained by actual school environments, rendering their viewpoints pragmatic but potentially less idealistic. This situation may impact research outcomes, as practitioners with extensive experience might prioritize operational feasibility over theoretical ideals. Consequently, the developed indicators may be more operationally oriented but potentially lacking in theoretical depth and innovativeness.

2 Literature Review

Digital Literacy refers to the ability to utilize computer and network resources. Paul Gilster [7] first introduced this concept in 1997, initially defining digital literacy as the capacity to comprehend and effectively use computer's extensive resources. Digital literacy is fundamentally the ability to use digital tools and platforms effectively [8]. This encompasses skills to search, evaluate, and responsibly utilize information from digital sources. Digital literacy is essential for navigating today's complex digital environments, as it enables individuals to critically assess information credibility. Research highlights that digital literacy not only involves technical proficiency but also critical thinking skills that help individuals evaluate the reliability of digital content [9]. Research indicates that digital competencies are increasingly crucial for teachers to effectively navigate modern education landscapes and engage students with technology-rich methodologies [10]. In October 2023, Taiwan's Ministry of Education, in the "K-12 Digital Teaching Guidelines 2.0," [11] defined "digital literacy" as the knowledge, abilities, and attitudes required to apply digital software, hardware resources, and methods in learning, life, and work contexts.

Digital instruction frequently leverages digital devices, mobile networks, digital teaching resources, and digital learning platforms, integrating these technologies into various disciplines and classroom settings. Digital learning has significantly transformed educational methodologies by integrating various digital technologies, enhancing both teaching strategies and student engagement. Strategies such as flipped teaching [12], cooperative learning [13], and adaptive learning [14] leverage digital resources to create dynamic learning environments. This integration not only personalizes education but also expands access

to diverse learning materials, fostering a more inclusive educational landscape. Digital learning resources enable students to connect with peers and educators worldwide, enriching their educational experience [13].

Due to the pandemic's impact, the educational sector underwent a period of online instruction, with educators and students experiencing diverse digital teaching modalities across physical and virtual environments. Prevalent digital instructional formats encompass synchronous digital teaching, asynchronous learning, hybrid approaches, and blended learning models that integrate in-person and remote instruction.

In synchronous e-learning, learners and instructors engage in real-time interactions through platforms like video conferencing. This format promotes immediate feedback and collaborative learning experiences. Examples include live webinars and virtual classrooms, which facilitate discussions and group activities.

Asynchronous e-learning allows learners to access materials at their convenience, promoting self-paced study. It includes resources such as recorded lectures, discussion forums, and online quizzes. This type is beneficial for learners with varying schedules, enabling them to learn without time constraints [15]. Blended learning combines both synchronous and asynchronous methods, offering a hybrid approach. It allows for flexibility, as learners can attend live sessions while also engaging with recorded content and online resources. This model enhances the learning experience by integrating various teaching methods and technologies [16].

Digital Teaching Competence (DTC) encompasses a comprehensive array of skills, knowledge, and attitudes that educational professionals must possess to effectively integrate digital tools into pedagogical practices. According to the DigCompEdu framework, digital competencies are delineated across six domains professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence requiring teachers to develop a holistic skill set aligned with these dimensions [17].

Moreover, the COVID-19 pandemic accentuated the urgent necessity for educators to possess robust digital competencies. Research demonstrates that numerous educational professionals felt unprepared when transitioning to online instruction, revealing significant disparities in their information technology skills [18-19].

The Delphi technique represents a structured communication methodology that relies on expert panels to achieve consensus on specific topics, frequently employed in educational research to identify capabilities essential for effective teaching. This technique facilitates a structured communication process among experts to reach consensus and determine core competencies required for effective digital instruction. The Delphi method is particularly germane when developing frameworks defining digital competencies, as it can identify critical areas educational professionals must prioritize by collecting insights from experienced educators and stakeholders, thereby understanding the most crucial capabilities for enhancing digital teaching skills in elementary education [20].

3 Methodology

To enhance elementary school teachers' digital teaching competencies, this research employs the Delphi technique [6], inviting experts and practitioners familiar with digital instruction in elementary schools. By implementing Delphi survey questionnaires, the study aims to consolidate expert consensus and establish digital teaching competency indicators for elementary school teachers. The research initially examined relevant literature to understand the digital teaching competencies elementary school teachers should possess. Through comprehensive analysis, five dimensions of digital teaching competencies were identified [21]:

1. Teachers' Digital Literacy
2. Digital Technology Assisted Teaching Competencies
3. Competencies in Integrating Digital Technology into Subject Learning
4. Digital Teaching Strategies and Formats
5. Information Technology Skills

As illustrated in Figure 1, these five dimensions constitute the research framework for assessing elementary school teachers' digital teaching competence. The corresponding questionnaire items were subsequently evaluated and refined through two rounds of the Delphi technique, involving experts and practitioners experienced in digital instruction at the elementary school level, to establish consensus on the essential competency indicators.

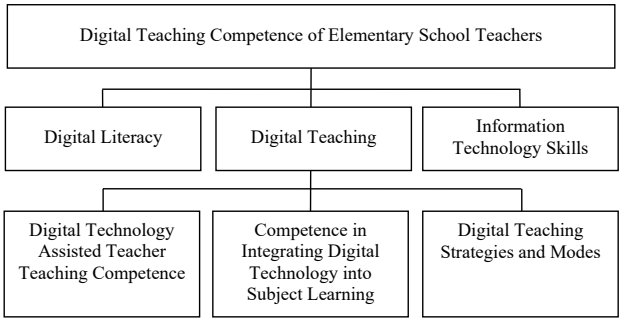

Figure 1. Research framework

To investigate digital teaching competencies for elementary school teachers, this research comprehensively gathered domestic and international literature, theoretical frameworks, educational policies, programs. legal regulations, and other officially published or website-hosted materials. The objective was to ensure document data richness and completeness, ultimately synthesizing and delineating the digital teaching competencies elementary school teachers should possess. The Delphi technique is a method designed to achieve group consensus. This technique involves creating questionnaires on a specific topic, inviting a group of experts (referred to as the Delphi panel) to express their opinions, and then collecting and synthesizing these insights to ultimately reach a collective agreement. The fundamental principle underlying the Delphi method is that structured individual

group predictions (or decisions) are more accurate than unstructured group predictions (or decisions).

After each round, an anonymous summary of the previous round's expert predictions and the rationales behind their judgments is provided. This approach encourages experts to modify their initial responses based on the answers of other group members. Throughout this iterative process, the range of answers progressively narrows, and the group converges toward a "correct" answer. The process ultimately terminates upon reaching predefined stopping criteria, with the final round's mean score or median determining the result.

This research implements the Delphi technique, with research subjects comprising experts and practitioners familiar with digital instruction in elementary schools, forming the Delphi panel. Based on purposive sampling, the questionnaire survey included a total of 11 participants who serve in roles such as academic directors, information technology coordinators, information secretaries, or teachers managing information-related teaching projects within schools.

This research conducted two rounds of Delphi technique questionnaire surveys, utilizing the "Research on Digital Teaching Competencies for Elementary School Teachers Delphi Technique Questionnaire". In this paper, the first-round Delphi survey questionnaire is based on research questions, literature review findings, reference to the Ministry of Education's "K-12 Digital Teaching Guidelines 2.0" released in October 2023, and expert opinions.

After collecting questionnaires, appropriate revisions and adjustments were made based on item appropriateness assessments and open-ended feedback, followed by the preparation of the second-round Delphi questionnaire. The two-round Delphi questionnaire formation process was conducted from February 5, 2024, to April 15, 2024, in Kaohsiung City, Taiwan.

3.1 First-Round Delphi Questionnaire

The first-round questionnaire comprised five sections: Part 1: Teacher Digital Literacy, Part 2: Digital Teaching-1: Digital Technology-Assisted Teaching Competencies, Part 3: Digital Teaching-2: Teachers' Competencies in Integrating Digital Technology into Subject Learning, Part 4: Digital Teaching-3: Digital Teaching Strategies and Formats, and Part 5: Information Technology Skills.

Totaling 44 items, panel members were requested to evaluate the appropriateness and agreement level of each indicator using a Likert 5-point scale: Extremely Inappropriate, 2: Inappropriate, 3: Neutral, 4: Appropriate, 5: Extremely Appropriate. Higher scores indicated greater appropriateness of digital teaching competency indicators, while lower scores suggested reduced appropriateness. An open-ended comments section was provided to gather additional insights.

3.2 Second-Round Delphi Questionnaire

After collecting the first-round questionnaire, statistical analysis of mean and standard deviation was conducted. Results were presented in the questionnaire, and indicators were modified and refined based on response feedback. Panel members were asked to re-evaluate by comparing first-round statistical results with their personal perspectives to understand differences and reach consensus.

3.3 Inter-rater Reliability (IRR)

Inter-rater Reliability (IRR) refers to the consistency or reliability of evaluation results when multiple raters assess the same set of subjects. It serves as a crucial indicator measuring the extent of subjectivity in the evaluation process, ensuring the reliability and validity of evaluation outcomes. To examine the scoring consistency among Delphi technique experts, and given that the number of raters exceeds two, this research employed Kendall's coefficient of concordance (Kendall ω) for analysis. Kendall's coefficient of concordance is a correlation measure that assesses the degree of correlation between multiple variables. It is particularly suitable for analyzing the consistency of K raters evaluating N items, or for multiple assessments of various items by the same rater at different time points.

The core of Kendall's coefficient of concordance lies in measuring the degree of association among multiple variables. Its value ranges from 0 to 1, with higher values indicating greater consistency among raters, while values closer to 0 suggest lower consistency. By utilizing Kendall's coefficient of concordance, the research can more objectively evaluate the consistency and reliability of survey results, thereby enhancing the study's overall reliability.

3.4 Qualitative Analysis

In the comments section of the Delphi technique survey questionnaire, it will interpret, analyze, and synthesize the opinions provided by the Delphi panel members. While preserving the original intent of the respondents, similar or identical opinions will be grouped together. For differing perspectives or insights, we will organize and conduct an in-depth analysis of their implications, ensuring that all viewpoints receive comprehensive consideration and understanding.

Therefore, the drafting digital teaching competency standards across five primary categories that teachers should possess: (1) Teacher Digital Literacy (TDL), (2) Digital Technology Assisted Teacher Teaching Competences (DTATTC), (3) Competence in Integrating Digital Technology into Subject Learning (IDT), (4) Digital Teaching Strategies and Modes (DTSM), (5) Information Technology Skills (ITS).

Before questionnaire development, two expert consultation meetings were arranged to obtain verification from experts regarding category determination, digital teaching competency indicators, and previously outlined items. Participants were invited based on their professional expertise. The participants included 5 members comprising local university professors and elementary school teachers, who possess professional knowledge in educational technology, science education, mathematics education, remote education, and educational psychology.

They assisted in reviewing the draft of digital teaching competencies that teachers should possess, which included 5 primary categories and 44 competency indicators.

Items were structured using open-ended questions, requesting respondents to provide their perspectives and comments on the statements included in the questionnaire. Comments from participants in the pilot study were taken into consideration to modify and refine the item list, ultimately developing the Delphi technique research instrument.

4 Data Analysis

Based on the Delphi technique survey results, data analysis was conducted to understand the recommendations and perspectives of Delphi panel members regarding the digital teaching competencies elementary school teachers should possess. The aim was to establish digital teaching competency indicators for elementary school teachers.

The research implemented two Delphi technique survey questionnaires on February 5th and March 25th, 2024. The Delphi panel consisted of eleven members-experts and practitioners familiar with digital instruction in elementary schools, including individuals serving as academic directors, information technology coordinators, information secretaries, or teachers managing information-related teaching projects within schools.

After each Delphi round, assessing importance and consensus is reasonable, followed by interpretation. Previous research typically utilized the median value and interquartile range distribution of group responses as references for importance and consensus [22].

Table 1 illustrates the results from the first and second rounds. Initially, the preliminary framework encompassed 44 digital teaching competencies that elementary school teachers should possess. Based on consensus criteria, after the first-round assessment, 22 competencies met the consensus standard and were marked as approved, 10 competencies failed to meet the expert consensus standard, with standard deviations greater than 1 or median values less than 4 [23]. Twelve competencies had their descriptions modified following expert recommendations to more appropriately reflect the digital teaching competencies elementary school teachers should possess. Modifications include as following:

"TDL1-Teachers can familiarize themselves with hardware equipment needed for digital teaching, such as tablets, touchscreens, VR helmets" was revised to "TDL1-TDL1-Teachers can familiarize themselves with hardware equipment needed for digital teaching, such as tablets, touchscreens, VR helmets, etc."

"TDL2-Teachers understand school networks and can enable simultaneous and smooth online access for all students" was modified to "TDL2-Teachers understand the school network and can enable the entire class to participate in online courses."

"DTSM1-Teachers can understand and apply 'flipped classroom' strategies" was changed to "DTSM1-Teachers can understand the "flipped classroom" strategy."

Table 1. The detailed results of two rounds of evaluation

Competence	Round 1	Round 2	Final	Competence	Round 1	Round 2	Final
TDL1	Modify	Pass		DTSM1	Modify	Pass	
TDL2	Modify	Failure	Delete	DTSM2	New	Pass	
TDL3	Pass	Pass		DTSM3	Modify	Failure	
TDL4	Failure	Failure	Delete	DTSM4	New	Pass	
TDL5	Failure	Failure	Delete	DTSM5	Modify	Pass	
TDL6	Pass	Pass		DTSM6	New	Failure	Delete
TDL7	Pass	Pass		DTSM7	Modify	Pass	
TDL8	Pass	Pass		DTSM8	New	Pass	
DTATTC1	Pass	Pass		DTSM9	Pass	Pass	
DTATTC2	Pass	Pass		DTSM10	Pass	Pass	
DTATTC3	Pass	Pass		DTSM11	Pass	Pass	
DTATTC4	Failure	Failure	Delete	ITS1	Failure	Failure	Delete
DTATTC5	Pass	Pass		ITS2	Pass	Pass	
DTATTC6	Pass	Pass		ITS3	Modify	Pass	
DTATTC7	Pass	Pass		ITS4	Failure	Pass	
DTATTC8	Pass	Pass		ITS5	Pass	Pass	
DTATTC9	Pass	Pass		ITS6	Pass	Failure	Delete
DTATTC10	Pass	Pass		ITS7	Modify	Pass	
DTATTC11	Failure	Failure	Delete	ITS8	Failure	Failure	Delete
IDT1	Pass	Pass		ITS9	Modify	Failure	Delete
IDT2	Failure	Failure	Delete	ITS10	Pass	Pass	
IDT3	Failure	Failure	Delete	ITS11	Modify	Pass	
IDT4	Pass	Pass		ITS12	Modify	Failure	Delete
IDT5	Failure	Failure	Delete	ITS13	Modify	Pass	

"DTSM-5 Teachers can understand and apply 'self-directed learning' strategies" was changed to "DTSM-5 Teachers can understand the 'self-directed learning' strategy."

"DTSM-7 Teachers can understand and apply 'adaptive learning' strategies" was changed to "DTSM7-Teachers can understand the "adaptive learning" strategy.".

"DTSM-3-Teachers can understand and apply 'collaborative learning' strategies" was revised to "Teachers can understand the "collaborative learning" strategy."

"ITS3-Teachers can skillfully utilize operating systems (desktop and mobile devices)" was modified to "ITS3-Teachers can use operating systems (desktop and mobile devices).".

"ITS9-Teachers can skillfully use tablets, including: understanding specifications, screen recording, file management, OTG" was changed to "ITS9-Teachers can proficiently utilize tablets, including understanding device specifications, screen recording capabilities, file management, OTG (On-The-Go) adapter functionality, and related features."

"ITS11-Teachers can use online platforms (Vimeo, Screencastify, Apowersoft, Youtube) for screen recording sharing" was modified to "ITS11-Teachers can use online platforms such as Vimeo, Screencastify, Apowersoft, and YouTube for screen recording and sharing.".

"ITS12-Teachers can edit audio and video using Evercam, Ocam, Bandicut, Bandicam software" was changed to "ITS12-Teachers can use common tool software (such as Kahoot, Quizlet, Blooket, Jamboard, Nearpod, Padlet, etc.) in teaching.".

"ITS13-Teachers can use common tool software like Kahoot, Quizlet, Blooket, Jamboard, Nearpod, Padlet" was modified to "ITS13-Teachers can use editing software (such as Evercam, Ocam, Bandicut, Bandicam, etc.) to edit audio and video.".

Additionally, 4 new capabilities (DTSM-2, DTSM-4, DTSM-6, and DTSM-8) were supplemented based on expert recommendations. These revised and consolidated competencies were submitted for the second round of assessment.

The second-round questionnaire commenced on March 25, 2024, distributed via mail or hand-delivered to the Delphi method panel members, totaling 11 copies, and was completed with a 100% retrieval rate by April 15, 2024. This round's framework encompassed 48 digital teaching competencies essential for elementary school teachers. Following the second-round evaluation, 30 capabilities met the consensus criteria. They were marked as approved, with descriptions of 3 capabilities refined based on expert suggestions to more accurately represent the digital teaching competencies required for elementary school educators.

"TDL1-Teachers can familiarize themselves with hardware equipment needed for digital teaching, such as tablets, touchscreens, VR helmets, etc.," was modified to "TDL1-Teachers know how to use the hardware equipment required for digital teaching, such as tablets, touch screens, VR headsets, etc.";

"TDL3-Teachers can proficiently use basic functions of digital teaching software and digital learning platforms" was revised to "TDL3-Teachers can use the basic functions of digital teaching software and digital learning platforms.";

"TDL6-Teachers can critically analyze and reflect on selected digital content or AI-generated content" was changed to "TDL6-Teachers can distinguish or judge the digital content or AI-generated content they have chosen.", and "ITS9-Teachers can proficiently utilize tablets, including understanding device specifications, screen recording capabilities, file management, OTG (On-The-Go) adapter functionality, and related features." was changed to "ITS9-Teachers can use tablets, such as understanding specifications, screen recording, file management, OTG (adapter), etc.". As a result, fifteen competencies did not meet the expert consensus standards after two rounds of Delphi Technique.

After two rounds of assessment, this study employed Kendall's Concordance Coefficient (Kendall's ω) to test the consistency of the 11 Delphi method panel members' perspectives on the appropriateness of the first round's 44 indicators and the second round's 48 indicators. The analysis results are presented in Table 2. The Kendall's ω coefficients were 0.397 ($p<0.001$) for the first round and 0.353 ($p<0.001$) for the second round. These results indicate a high level of consensus among the 11 expert panel members regarding the appropriateness of each indicator, with both rounds achieving statistical significance [24]. Consequently, a third round of questionnaire survey was deemed unnecessary.

Table 2. Kendall's coefficient of concordance

	Round1	Round2
Number of experts	11	11
Number of Indicators	48	48
Kendall's ω Test	0.397	0.353
Chi-square	174.562	169.210
df	10	10
Sig.	0.000	0.000

Through these two rounds of evaluation, a competency framework comprising 33 capabilities was ultimately established (refer to Appendix 1 for comprehensive details), which was subsequently organized into those above five distinct domains: (1) Teacher Digital Literacy (TDL, with five competencies), (2) Digital Technology Assisted Teacher Teaching Competence (DTATTC, with nine competencies), (3) Competence in Integrating Digital Technology into Subject Learning (IDT, with two competencies), (4) Digital Teaching Strategies and Modes (DTSM, with ten competencies), (5) Information Technology Skills (ITS, with seven competencies).

The findings confirm expert consensus on teachers' foundational digital device operational skills (TDL1) and digital platform proficiency (TDL3) (median=4) as highlighted in studies emphasizing the significance of teachers' digital literacy in building foundational digital competencies. Notably, information security and privacy protection awareness (TDL7) received the highest rating (median=5), emphasizing the paramount importance of

digital security consciousness in teacher competencies.

The digital assessment and real-time learning performance monitoring Competence (DTATTC10) garnered the highest rating (median=5). This underscores the crucial role of immediate assessment and feedback in enhancing digital teaching effectiveness. Significantly, the application of generative AI in lesson preparation and teaching activities (DTATTC11) failed to achieve expert consensus and was eliminated, reflecting a cautious approach toward AI integration in education.

The application of multimedia and interactive digital materials (IDT1) received the highest rating (median=5), highlighting the significance of integrating technology with subject content effectively.

Both flipped classroom (DTSM1) and collaborative learning (DTSM3) strategies achieved high consensus (IQR=0), indicating the growing importance of innovative teaching models in the digital era.

Operating system proficiency (ITS3) received the highest rating (median=5), emphasizing the importance of fundamental digital skills. However, advanced skills such as website design (ITS4) and programming (ITS6) were eliminated, suggesting these are not considered core competencies for elementary school teachers.

The proficiency in basic generative AI functions (TDL4) failed to achieve expert consensus (median=3) and was eliminated. This suggests that AI technology application in educational settings remains in an exploratory phase, aligning with the view that AI's role in education is still developing in scope and focus, with a need for careful implementation to address challenges effectively. This also indicates that teachers' mastery of AI tools should not be considered a core evaluation criterion.

Interestingly, regarding AI content discernment capabilities, while "teachers' ability to distinguish between accurate digital information and AI-generated content" (TDL5) was eliminated (median=3), "teachers' ability to discern or evaluate selected digital content or AI-generated content" (TDL6) was retained (median=4). This suggests that teachers' content evaluation and selection abilities are more crucial than mere AI/non-AI content identification skills. AI technologies, including content discernment tools, underscore the need for educators to critically assess digital resources, which has been highlighted as vital for successful AI integration in education.

Awareness of AI ethics and regulations (TDL8) received expert endorsement (median=4), aligning with the emphasized importance of AI ethics education, particularly concerning personal data protection and intellectual property rights. This reflects a consensus on the significance of ethics education in AI, mirroring the broader need for ethical frameworks in educational technologies to ensure responsible AI use in classrooms.

5 Conclusion

This study investigates the digital teaching competencies that elementary school teachers should possess when conducting digital teaching. The research focused on elementary school teachers, employing the Delphi method by inviting 11 educators serving as academic directors, information technology coordinators, information technology secretaries, or teachers involved in information-related teaching projects. Through two rounds of questionnaire surveys, the research ultimately synthesized 33 digital teaching competency indicators for elementary school teachers. The following section elaborates on the conclusions derived from the Delphi survey results and the level of consensus achieved.

Based on the results of two rounds of Delphi method questionnaire surveys, the expert panel unanimously agreed on the high appropriateness of the 33 indicators across five dimensions: "Teacher Digital Literacy", "Digital Technology-Assisted Teaching Competence", "Teachers' Competence in Integrating Digital Technology into Subject Learning", "Digital Teaching Strategies and Approaches", and "Information Technology Skills".

Generative AI is an emerging technology with which most teachers have limited experience. Effectively utilizing generative AI requires significant time investment to understand its capabilities, let alone implementing it in educational settings [25]. Moreover, the substantive benefits of generative AI for teaching and student learning remain empirically unverified. Consequently, the Delphi method expert panel generally assigned low scores to generative AI-related indicators, suggesting they are not considered essential digital teaching skills for teachers [26].

The expert panel argued that teachers need not necessarily create digital learning materials themselves but should instead focus on identifying and utilizing appropriate educational resources [27]. Producing digital materials requires specialized technical skills, and given the diverse professional backgrounds of educators, applying a uniform standard is challenging. Therefore, indicators related to self-producing digital learning materials received consistently low scores from the Delphi method expert panel.

The composition of the Delphi method panel members significantly influenced the evaluation of research indicators in this study. The selected experts primarily comprised practitioners in educational settings, such as teachers and part-time administrative staff, with a notable absence of academic theorists. Consequently, during the questionnaire survey, experts' opinions were likely constrained by practical school environment considerations, resulting in recommendations that were more pragmatic but less idealistic. This approach potentially impacts the research outcomes by prioritizing immediate, implementable strategies over broader, more innovative conceptualizations of digital teaching competencies.

5.1 Recommendations for Educational

Administrative Authorities: The purpose of establishing digital teaching competency indicators is to provide elementary school teachers with directional guidance for enhancing their digital teaching literacy. Therefore, administrative authorities should formulate appropriate

indicators that effectively support and advance teaching practices.

5.2 Recommendations for Teacher Training and Professional Development:

Educational administrative units should prioritize digital teaching curricula in teacher training institutions, developing training programs based on suitable indicators to cultivate practical teaching application skills. Similarly, for in-service teachers, authorities should organize practical courses and relevant workshops on implementing digital technology in teaching, including topics such as generative AI. This structured approach provides teachers with a solid foundation for developing their digital teaching competencies and ensures professional growth in digital pedagogy.

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Appendix 1. The detailed results of second round Delphi technique

Competence	Median	IQR	SD	Final
Teacher Digital Literacy				
TDL1-Teachers know how to use the hardware equipment required for digital teaching, such as tablets, touch screens, VR headsets, etc	4	1	0.820	
TDL2-Teachers understand the school network and can enable the entire class to participate in online courses	4	2	1.044	Delete
TDL3-Teachers can use the basic functions of digital teaching software and digital learning platforms	4	1	0.944	
TDL4-Teachers can become proficient in using various basic functions of generative AI	3	0	0.632	Delete
TDL5-Teachers can distinguish between accurate digital information and AI-generated content	3	1	0.809	Delete
TDL6-Teachers can distinguish or judge the digital content or AI-generated content they have chosen	4	1	0.905	
TDL7-Teachers know how to use digital tools or platforms safely and are concerned about protecting personal privacy on the Internet	5	1	0.934	
TDL8-When using digital tools and generative AI, teachers can follow concepts of information security, copyright, and the rule of law, and protect personal information from being improperly used when using generative AI	4	1	0.751	
Digital Technology Assisted Teacher Teaching Competence				
DTATTC1-Teachers can apply the course structure and content of digital learning platforms or use generative AI to assist in course planning and improve preparation efficiency	4	1	0.688	
DTATTC2-Teachers can apply digital collaboration tools for joint preparation and teaching design planning	4	1	0.674	
DTATTC3-Teachers can integrate digital teaching materials from different sources and formats into digital teaching courses	4	1	0.751	
DTATTC4-Teachers can use digital tools or platforms to record and analyze reports to understand students' learning progress and difficulties, and develop appropriate teaching strategies	4	2	1.044	Delete
DTATTC5-Teachers can use digital tools or platforms to enhance real-time interaction and sharing between teachers and students, and solve learning misconceptions	4	1	0.701	
DTATTC6-Teachers can guide students to use digital tools or platforms for synchronous or asynchronous discussion, interaction, and collaborative editing	4	2	0.831	
DTATTC7-Teachers can use different digital search tools, set appropriate keywords, and search for course-related learning resources	4	1	0.905	
DTATTC8-Teachers can use digital tools to guide students to create works and enhance their individual or group creativity	4	1	0.701	
DTATTC9-Teachers can guide students to use digital tools or platforms to display and present individual or group works	4	1	0.894	
DTATTC10-Teachers can use digital tools or platforms for assessment and real-time monitoring of learning performance	5	1	0.688	
DTATTC11-Teachers can use generative AI for lesson preparation or integrate generative AI into teaching activities	3	1	0.924	Delete
Competence in Integrating Digital Technology into Subject Learning				
IDT1-Teachers can apply multimedia or interactive digital teaching materials to enhance students' learning interest and motivation	5	1	0.467	
IDT2-Teachers can apply or create digital teaching materials to concretely present abstract concepts in subject areas	4	2	1.044	Delete
IDT3-Teachers can apply or create digital teaching materials to simulate virtual spatio-temporal scenarios and present subject-specific teaching content, such as historical scenes or lunar phases	3	3	1.401	Delete
IDT4-Teachers can apply or create digital teaching materials to complement subject-specific assessments and achieve the effect of learning proficiency	4	1	0.505	

Competence	Median	IQR	SD	Final
IDT5-Teachers can apply or create digital teaching materials to simulate scenarios or plan designs, such as virtual laboratories that allow students to safely practice operations without being exposed to real dangerous or harmful environments	3	2	1.25	Delete
Digital Teaching Strategies and Modes				
DTSM1-Teachers can understand the “flipped classroom” strategy	4	0	0.632	
DTSM2-Teachers can use digital technology to assist “flipped classroom”	4	1	0.647	
DTSM3-Teachers can understand the “collaborative learning” strategy	4	0	0.405	
DTSM4-Teachers can use digital technology to assist “collaborative learning”	4	1	0.786	
DTSM5-Teachers can understand the “self-directed learning” strategy	4	1	0.701	
DTSM6-Teachers can use digital technology to assist “self-directed learning”	3	1	0.688	Delete
DTSM7-Teachers can understand the “adaptive learning” strategy	4	1	0.647	
DTSM8-Teachers can use digital technology to assist “adaptive learning”	4	2	0.775	
DTSM9-Teachers can understand and operate the “synchronous digital teaching” mode	4	1	0.505	
DTSM10-Teachers can understand and operate the “asynchronous digital teaching” mode	4	1	0.647	
DTSM11-Teachers can understand and operate the “blended digital teaching” mode	4	1	0.647	
Information Skills				
ITS1-Teachers can use multimedia editing to create teaching materials	4	1	1.095	Delete
ITS2-Teachers can use cloud services and cloud storage	4	1	0.522	
ITS3-Teachers can use operating systems (desktop and mobile devices)	5	1	0.505	
ITS4-Teachers can design teaching websites, such as HTML commands and syntax, FrontPage, Blog, Facebook, etc	3	2	1.214	Delete
ITS5-Teachers can operate Office suite software	4	1	0.522	
ITS6-Teachers can use programming languages, such as Scratch	3	2	1.221	Delete
ITS7-Teachers can operate Office 365 (cloud-based work)	4	1	0.905	
ITS8-Teachers can use FTP (File Transfer Protocol)	3	1	1.206	Delete
ITS9-Teachers can use tablets, such as understanding specifications, screen recording, file management, OTG (adapter), etc	4	1	1.036	Delete
ITS10-Teachers can use document cameras	4	1	0.701	
ITS11-Teachers can use online platforms such as Vimeo, Screencastify, Apowersoft, and YouTube for screen recording and sharing	4	2	0.982	
ITS12-Teachers can use common tool software (such as Kahoot, Quizlet, Blooket, Jamboard, Nearpod, Padlet, etc	3	1	1.044	Delete
ITS13-Teachers can use editing software (such as Evercam, Ocam, Bandicut, Bandicam, etc	4	1	0.751	