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Developing a competency framework for smart natural and social sciences teaching in primary teacher education: A Delphi study

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Abstract

The rapid rise of artificial intelligence (AI), learning analytics, and intelligent educational technologies has created new competency demands for pre-service primary teachers. Current teacher competence frameworks, however, provide extensive guidance on digital competence but limited support for subject-specific teaching in the natural and social sciences, where inquiry, interdisciplinary integration, evidence-informed pedagogy, and technology-enhanced instruction are essential. This study developed and validated a competency framework for Smart Natural and Social Sciences Teaching based on a three-round modified Delphi method. The framework was developed from an extensive literature review and iteratively evaluated and refined by 20 experts in primary education, science education, educational technology, and educational assessment. Expert consensus was examined using descriptive statistics, agreement percentages, the I-CVI, and the S-CVI/Ave. The resulting framework comprises five competency domains, eighteen component competencies, and 112 performance indicators covering professional knowledge, pedagogical design, instructional implementation, assessment and learning analytics, and professional reflection and innovation. The mean scores in the last Delphi round ranged from 4.42 to 4.76; the percentages of agreement ranged from 90% to 100%; the I-CVI values ranged from 0.90 to 1.00; and the S-CVI/Ave was 0.96, indicating strong expert consensus and excellent content validity. The framework defines smart teaching competence as the integration of digital technologies, AI, and learning analytics into core professional teaching practices. The basis for curriculum development, competency-based assessment, teacher preparation, and future empirical research in Smart Education is validated and operationalized by experts.

Keywords: Artificial intelligence, Competency framework, Delphi study, Learning analytics, Natural and social sciences, Pre-service primary teachers, Smart education.

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Contents

Contribution of this paper to the literature

This study contributes to the literature by developing a subject-specific competency framework for smart teaching in the natural and social sciences, an area insufficiently covered by generic digital competence frameworks. The framework combines professional expertise with pedagogical, technological, assessment and reflective competencies and operationalizes them through expert-validated performance indicators.

1. Introduction

The rapid development of AI, learning analytics, intelligent assessment, adaptive learning technologies, and generative AI has fundamentally changed the landscape of smart education. Smart education is increasingly described by recent research not only as the digitalization of teaching and learning, but as an intelligent, data-informed educational ecosystem where emerging technologies continuously support instructional design, personalized learning, formative assessment, adaptive instruction, and evidence-based pedagogical decision-making (Ayeni, Al Hamad, Chisom, Osawaru, & Adewusi, 2024; Holmes, Bialik, & Fadel, 2019; OECD, 2021; UNESCO, 2024). Further evidence of generative AI's expansion of teachers' professional roles comes from recent studies that show it is assisting teachers with lesson planning, instructional design, assessment, feedback generation, and reflective practice, thus reframing the focus of smart education from the adoption of technology to the pedagogically meaningful integration of intelligent technologies into professional practice (Carrión Candel, Lomba Pérez, Berd-Gómez, & González-Martín, 2026; Tang & Zhong, 2026; Vivas-Urias, Obispo-Díaz, & Ruiz-Rosillo, 2026). Together, these studies suggest an emerging consensus that the educational value of emerging technologies is less a function of the technologies themselves than teachers' pedagogical choices about how to meaningfully integrate the technologies into teaching and learning.

Consequently, a major conceptual shift has taken place in the research on teacher competence. Pedagogical Content Knowledge (PCK) was an early theory of teacher competence which combined the knowledge of disciplines and pedagogy, and later models developed this perspective by incorporating technological knowledge into teachers' professional competence (Grossman, 1990; Mishra & Koehler, 2006; Shulman, 1987). However, more recent studies on teacher competence perceive it as an adaptive and context-dependent professional ability that combines disciplinary knowledge, pedagogy, technology, ethics, data literacy, and continuous professional learning in real teaching settings (Alghanaim, Rogers, Hart, & Finn, 2025; Blömeke, Gustafsson, & Shavelson, 2015; Darling-Hammond & Bransford, 2007; Révai & Guerriero, 2017). This theoretical evolution is reflected in contemporary competency frameworks such as DigCompEdu, the UNESCO AI Competency Framework for Teachers, and the OECD AI and Digital Education frameworks which increasingly focus on teachers' capacities to integrate digital technologies and AI into curriculum design, instructional implementation, assessment and professional learning, rather than focusing only on technology-related skills (OECD, 2021; Redecker, 2017; UNESCO, 2024). The confluence of these developments suggests a substantial change in teacher education from technology-oriented competence to AI-integrated professional competence.

These developments are of particular importance for the teaching of natural and social sciences at primary schools. This learning area consists of Natural and Social Sciences (Grades 1-3), Science (Grades 4-5) and History and Geography (Grades 4-5) in Vietnam's 2018 General Education Curriculum (MOET, 2018a, 2018b, 2018c). Although the disciplines of these subjects are different, they share pedagogical characteristics, emphasizing observation, inquiry, investigation, evidence-based reasoning, real-life learning experiences, interdisciplinary understanding, and ongoing formative assessment. These features gradually develop students' scientific literacy, social awareness, environmental consciousness, historical thinking, geographical understanding, and problem-solving skills through authentic engagement with natural and social phenomena (Black & Wiliam, 2009; Bybee, 2013; Bybee, 2019; MOET, 2018a; National Research Council, 2012; NGSS Lead States, 2013). Thus, effective teaching involves pre-service primary teachers' competencies to design inquiry-oriented learning environments, facilitate interdisciplinary investigations, incorporate digital resources and AI into authentic learning activities, and employ formative assessment to support students' continuous learning and development (Black & Wiliam, 2009; Bybee, 2013; Darling-Hammond & Bransford, 2007; Magnusson, Krajcik, & Borko, 1999; NGSS Lead States, 2013).

With the increasing complexity of teaching in Smart Education, several competency frameworks have been developed to contribute to teachers' preparation and professional development. Effective teaching, according to foundational frameworks like PCK and TPACK, is the integration of disciplinary knowledge, pedagogy and technology (Grossman, 1990; Mishra & Koehler, 2006; Shulman, 1987). More recent frameworks such as DigCompEdu, the UNESCO AI Competency Framework for Teachers and OECD initiatives further widen this perspective by integrating digital competence, AI, ethics, data literacy and professional learning into teachers' professional competence (OECD, 2021; Redecker, 2017; UNESCO, 2024). These frameworks have contributed significantly to teacher education by providing an overarching guideline for integrating emerging technologies in various educational settings. However, they intentionally serve as generic frameworks applicable across educational systems and subject areas. As a result, they offer little conceptual assistance for making sense of how competency expectations should be interpreted in disciplines with quite different epistemological structures and pedagogical processes.

This limitation is most evident in science education in the natural and social sciences. Research in science education consistently shows that successful teaching hinges on competencies in inquiry, evidence construction, conceptual explanation, authentic investigation, interdisciplinary reasoning, and problem solving that are closely tied to the epistemological features of the discipline (Bybee, 2013; Magnusson et al., 1999; National Research Council, 2012; NGSS Lead States, 2013). The development of smart education is about bringing AI, learning analytics, digital learning resources, personalized learning and intelligent assessment into classroom practice. Skills for teaching natural and social sciences are often very different from general digital competence (Ayeni et al., 2024; Holmes et al., 2019; Mousa, 2025; OECD, 2021; Tang & Zhong, 2026; UNESCO, 2024). Consequently, an important theoretical question emerges: if smart education fundamentally reshapes the pedagogical processes through which natural and social sciences are taught, can teacher competence continue to be conceptualized primarily as a generic construct across disciplines? Addressing this question requires a competency framework that explicitly conceptualizes smart teaching competence from a subject-specific perspective. However, such competency expectations remain insufficiently specified in the current literature.

To address this theoretical and practical gap, the present study aimed to develop and validate a competency framework for smart teaching in the natural and social sciences for pre-service primary teachers using a three-round Delphi method. Rather than proposing another generic digital competency framework, this study conceptualizes how the pedagogical characteristics of natural and social sciences should shape competency expectations within smart education. The resulting framework contributes to the literature in three ways. First, it provides a subject-specific conceptualization of smart teaching competence by integrating technological capabilities into the professional processes of curriculum analysis, pedagogical design, instructional implementation, assessment, and reflective practice. Second, it establishes an expert-validated competency framework to support curriculum development, competency-based assessment, and the professional preparation of pre-service primary teachers. Third, it provides theoretical support for future research on the development, evaluation, and application of subject teaching competence in smart education.

2. Theoretical Background

2.1. Teaching Competence in the Context of Smart Education

Teaching competence is increasingly understood as a professional capability that is context-dependent and enacted in authentic teaching practice, rather than as a static collection of knowledge, skills, or technological abilities (Blömeke et al., 2015; Révai & Guerriero, 2017). Thus, significant changes in educational settings inevitably lead to changes in the professional processes of teaching and the competencies that teachers are expected to demonstrate. Smart education is such a transformation in appearance. Smart education not only applies digital technologies to classrooms, but it also transforms teachers' understanding of curricula, designing learning experiences, facilitating classroom interaction, assessing student learning, and improving instructional practice (Hase & Kuhl, 2024). In this sense, professional competence is increasingly understood as the ability to integrate intelligent technologies into these professional processes rather than the acquisition of additional digital skills (Filo, Rabin, & Mor, 2024).

This is reflected in the development of research into teachers' competence. Previous versions, notably PCK, focused on the teacher's ability to translate disciplinary knowledge into meaningful learning opportunities (Shulman, 1987). Later, the Technological Pedagogical Content Knowledge (TPACK) framework expanded this view further by including technology as an integral part of pedagogical decision-making, not as a stand-alone technical skill (Mishra & Koehler, 2006). More recent studies propose a more fluid understanding of competence as context-dependent and performed in professional practice, highlighting teachers' ability to respond flexibly to the increasing dynamism of instructional settings (Blömeke et al., 2015; Darling-Hammond & Bransford, 2007; Révai & Guerriero, 2017). In general, these views mean that teaching competence develops with the changes in the professional demands of teaching (Coppe et al., 2024).

These changing professional demands are particularly visible in Smart Education. AI, learning analytics, intelligent tutoring systems and digital learning environments are not only used as instructional tools, but they increasingly support teachers throughout the whole instructional cycle, including curriculum interpretation, instructional design, classroom implementation, learning assessment and reflective improvement (Holmes et al., 2019; OECD, 2021; UNESCO, 2024). Intelligent technologies, as opposed to earlier generations of educational technology, actively support teachers' professional decision-making by helping them analyze evidence of learning, individualize instruction, provide timely feedback, and iteratively improve pedagogical strategies (Gerard, Spitulnik, & Linn, 2010). Therefore, their educational value lies not in the technology itself but in enhancing teachers' professional judgment within the teaching process (Heitink, Voogt, Verplanken, van Braak, & Fisser, 2016).

This understanding is consistently reflected in current international competency frameworks. Frameworks such as DigCompEdu (Redecker, 2017), the UNESCO AI Competency Framework for Teachers (UNESCO, 2024), and the OECD framework for AI and digital education (OECD, 2021). All emphasize the integration of digital technologies and AI into curriculum planning, instructional delivery, assessment, professional collaboration, and ongoing professional learning. Though these frameworks differ in scope and emphasis, they share the perspective of technology as a way of improving professional teaching practice and not a domain of competency (Yang, Sun, Lin, & Zhu, 2024) like the one proposed here.

But one big theoretical limitation remains. Current competency frameworks are consciously designed to be relevant for all educational levels and subject areas. They therefore introduced the idea that teaching competence is a generic professional competence, and there is little theoretical basis for the discipline with different epistemological foundations, inquiry methods, and teaching modes (Hordern & Brooks, 2024). This restriction is particularly relevant for Smart Education, where the educational value of intelligent technologies is determined less by their technical features than by the extent of support for discipline-specific teaching processes (Crompton & Burke, 2024). Therefore, to grasp teaching competence in Smart Education, we need to move beyond generic competency frameworks and adopt subject-specific conceptualizations that reflect the specific professional processes by which individual curriculum areas are taught.

2.2. Teaching Competence in Subject-Specific Contexts

Teaching competence means the professional skills required for different teaching contexts. Recent research, however, shows that its implementation is largely shaped by the epistemological features and pedagogical needs of particular disciplines (Suh, Hand, Dursun, Lammert, & Fulmer, 2023). Thus, competence is manifested in different ways across subjects and is constructed through teachers' interpretation of disciplinary knowledge, their organization of learning experiences, their facilitation of classroom inquiry, and their assessment of student learning (Kind, 2009; Magnusson et al., 1999). Understanding of teaching competence therefore requires moving beyond generic descriptions of competence to conceptualizations that reflect the professional practices of particular curriculum areas.

This perspective has been especially influential in science education where subject-specific teaching competence means not only mastery of scientific concepts but also the ability to design inquiry-based learning, facilitate scientific reasoning, guide evidence construction, and support students in developing conceptual understanding through authentic investigation (Bybee, 2013; National Research Council, 2012; Sandoval & Reiser, 2004). Today, social sciences are taught through historical inquiry, geographical reasoning, critical analysis of social issues, and interpretation of a variety of forms of evidence. Teachers should provide learning opportunities that develop analytical thinking and that promote educated citizenship (Barton & Ho, 2022). Such disciplinary features influence teaching approaches, curriculum interpretation, classroom interactions, assessment, and reflective enhancement. In the same vein, the integrated natural and social science subjects in primary education point to the importance of a subject-specific perspective. This differs from single science or social science subjects, as it integrates scientific research and the investigation of social, cultural, historical, and geographical phenomena to support young learners in understanding relationships between humans, society, and the natural world (MOET, 2018a, 2018b, 2018c; NCCA, 2024). In this respect, teaching should incorporate interdisciplinary knowledge, inquiry-based pedagogy, experiential learning and authentic assessment in learning experiences appropriate for the cognitive development of children (MOET, 2018a). Teaching competence in this context involves more than a general pedagogical competence; it requires professional judgment closely related to the specific characteristics of the subject.

This requirement is even more emphasized with the development of smart education. AI, digital learning resources, simulation technologies, and learning analytics have no educational value in themselves outside disciplinary contexts (Dai & Ke, 2022). Their effectiveness relies on how they support subject-specific teaching processes, such as designing inquiry activities, facilitating evidence-based investigation, examining students' conceptual development, and providing adaptive feedback throughout the learning process. Consequently, intelligent technologies should be viewed not as separate competency domains but as pedagogical resources that enhance discipline-specific professional practice.

Taken together, these perspectives suggest that teaching competence in Smart Education cannot be adequately conceptualized using only generic digital competency frameworks. Rather, it should be understood in relation to the distinctive professional processes by which specific disciplines are taught, especially when intelligent technologies support these processes. This approach underpins the definition of Smart Natural and Social Sciences Teaching Competence as a subject-specific professional capability, which is further elaborated on in the following section.

2.3. Smart Natural and Social Sciences Teaching Competence

Teaching competence in smart education should be conceptualized through two complementary theoretical perspectives. First, teaching competence is realized in professional teaching processes, in which intelligent technologies are resources to support teachers' professional judgment, not as separate domains of competence (Blömeke et al., 2015; Heitink et al., 2016; UNESCO, 2024). Secondly, the epistemological features, curriculum goals, and didactic methods of the disciplines influence these professional processes, implying that competence should be understood in subject-specific contexts rather than generic competency frameworks (Bybee, 2013; Hordern & Brooks, 2024; MOET, 2018a). These conceptual perspectives are especially relevant for the teaching of natural and social sciences in primary education. The natural and social sciences are multidisciplinary subjects which integrate scientific investigation with the exploration of natural, social, historical, geographical, cultural and environmental phenomena. Learners can develop a holistic understanding of themselves, society and the natural world (Cohen, Novis-Deutsch, Kashi, & Alexander, 2024; MOET, 2018a). Good teaching, then, combines disciplinary knowledge with the promotion of inquiry-based, interdisciplinary, and experiential learning. Students can experience real-world phenomena, construct explanations based on evidence, and apply their knowledge in real-world contexts (Bybee, 2013; Furtak, Seidel, Iverson, & Briggs, 2012; National Research Council, 2012).

Smart education: Intelligent technologies have a great influence on professional teaching activities. Teachers are increasingly supported by AI, learning analytics, intelligent assessment systems and digital learning resources to analyze curriculum requirements, design adaptive learning experiences, facilitate inquiry, monitor student progress, interpret assessment data and continuously improve instructional practices (Hamdani, Suherman, Darmawan, & Permana, 2025; Holmes et al., 2019; OECD, 2021; UNESCO, 2024). The educational value of these technologies lies not in the tools themselves but in the potential to improve teachers' professional reasoning and pedagogical decision-making in the teaching process (Gerard et al., 2010; Heitink et al., 2016). Therefore, the integration of intelligent technologies should be seen as an integral part of subject-specific teaching competence, not as an additional technological skill. The study defines smart teaching competence in natural and social sciences as a subject-specific professional competence. This skill facilitates pre-service primary teachers' integration of intelligent technologies into curriculum interpretation, pedagogical design, instructional delivery, learning assessment, and reflective improvement in the instruction of natural and social sciences. The conceptualization stresses that the construction of competence cannot be reduced to individual digital skills but must be understood as the coherent integration of knowledge of the subject, pedagogy, and intelligent technologies in authentic teaching practice. This viewpoint serves as the conceptual foundation for the development of the preliminary competency framework, which was further refined and validated through the Delphi process.

3. Methodology

3.1. Research Design

A three-round modified Delphi method was adopted to develop and validate a competency framework of smart natural and social sciences teaching for pre-service primary teachers. The Delphi method is popular in education research, especially where expert knowledge is dispersed, and a shared understanding of a complex concept has not yet been reached (Hasson, Keeney, & McKenna, 2000; Hsu & Sandford, 2007; Keeney, Hasson, & McKenna, 2010; von der Gracht, 2012). In the present study, no existing framework comprehensively addressed the competencies required for smart natural and social sciences teaching. Therefore, expert consultation was undertaken to review, refine, and validate a preliminary competency framework.

A modified Delphi approach was selected because the first round did not begin with completely open-ended questions. Prior to expert consultation, a preliminary competency framework had been developed from the theoretical foundations presented in Section 2 and a review of the literature on teaching competence, smart education, natural and social sciences education, and competency-based teacher education. This preliminary framework was presented to the expert panel as a working draft for critical review rather than as a fixed model. Experts were asked to review the structure, identify limitations, make recommendations for revision, and propose additional competencies, as appropriate.

The Delphi process consisted of three consecutive rounds. During the first round, the preliminary framework was reviewed qualitatively. The expert panel examined the competency domains, component competencies, and performance indicators with particular attention to their completeness, logical organization, and relevance to smart natural and social sciences teaching. Recommendations concerning the retention, revision, merger, separation, removal, or addition of competency elements were collected together with written comments. These comments informed the first revision of the framework.

The revised framework was subsequently evaluated in the second round. Each competency was assessed using four criteria: relevance, necessity, clarity, and measurability. The quantitative ratings were integrated with the qualitative comments in order to identify areas that needed further revision and to understand the reasons for differences between experts.

The revised framework was circulated for a third Delphi round following a second revision. The expert panel reviewed the revised version and determined whether the residual concerns had been adequately addressed. Once no major changes were suggested and consensus was reached, the competency framework was completed. Figure 1 shows the general research process.

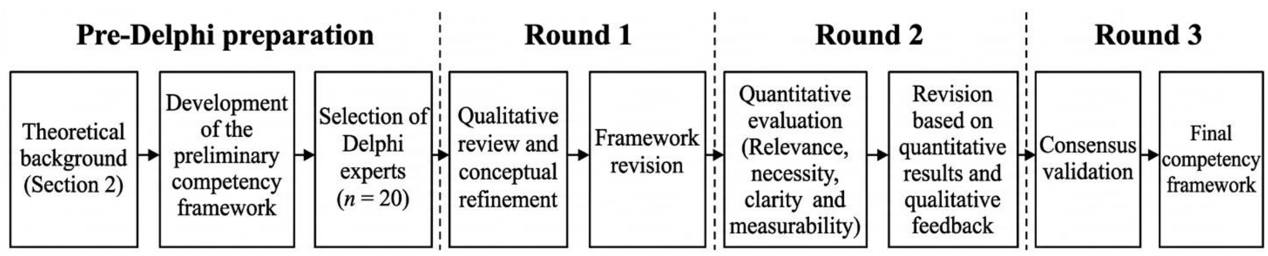

Figure 1. Three-round Delphi process for developing and validating the competency framework for smart natural and social sciences teaching competence.

3.2. Participants

The Delphi panel comprised 20 suitably qualified experts. The group consisted of experts in primary education, science education, educational technology, educational measurement and assessment, and related fields. Experts were selected if they met three criteria: at least five years of professional experience in teacher education, curriculum development, educational technology, or educational assessment; experience in research or professional work related to primary education, competency-based teacher education, or Smart Education; and willingness to take part in all three Delphi rounds. Experts from various fields were included so that the framework was reviewed from teaching and technology perspectives. Elementary and science educators examined the proposed competencies' appropriateness and alignment with their disciplines. Education technology experts reviewed the framework to ensure that it covered Smart Education, artificial intelligence, digital learning resources, and learning analytics. Educational measurement and assessment experts reviewed the competency statements and performance indicators for clarity, measurability, and validity. The best results of the Delphi method can be obtained with a small group of highly qualified experts. Therefore, a panel of 20 was selected. Research has shown that consensus is often achieved with 15-30 subject matter experts (Alghanaim et al., 2025).

3.3. Delphi Process

The modified Delphi process was conducted from November 2024 to May 2026 and involved 3 rounds of expert consultation. A preliminary competency framework was developed based on the literature review and the relevant theoretical basis before the first round. The framework underpinned expert consultation and was iteratively refined through the study. Feedback from experts from each round was analyzed, and a revised version of the framework was prepared for the subsequent round.

In the first round, experts examined the draft competency framework, comprising proposed competency domains, component competencies and performance indicators. They examined the suitability, completeness and relevance of these elements for smart teaching of natural and social sciences. Experts provided written comments and recommendations on whether particular competency elements should be retained, revised, merged, separated, removed or supplemented. They were also asked to suggest other competencies or performance indicators where appropriate. These recommendations were synthesized into the revised framework for the second round.

In the second round, the revised framework was evaluated by experts on four criteria: relevance, necessity, clarity, and measurability. Competencies and performance indicators were rated quantitatively, and the experts were asked to comment on their ratings and to identify sections needing further refinement. Both the quantitative ratings and the qualitative feedback informed the revisions made before the third round.

The third round was conducted to determine whether consensus had been achieved after the second-round revisions. The experts reviewed the updated framework, received a summary of changes made since Round 2, and re-assessed each competency component. As no substantial additional revisions were proposed, the competency framework was considered to have reached an acceptable level of expert consensus and was finalized.

All 20 experts took part in all three rounds of the Delphi, resulting in a 100% response rate for the study as a whole.

3.4. Research Instrument

The main research tool was a structured Delphi questionnaire, adapted from the first competency framework in the literature review and key theories. This questionnaire was used in the Delphi process to refine the framework using both qualitative and quantitative evaluation.

The questionnaire was divided into two sections. In the first section, experts were asked to evaluate the proposed competency framework (domains, components, and performance indicators). In the second section, open-ended questions allowed experts to comment on the structure, completeness, wording, relevance, and measurability of the framework. Experts can suggest changes, additions, deletions, or reorganizations as needed.

After each Delphi round, the questionnaire was updated to reflect changes in the competency framework; however, its overall structure remained the same. The first round was mostly qualitative feedback to consider and develop the initial framework. In rounds two and three, it used both quantitative ratings and qualitative comments to evaluate the revised framework and to identify areas for further work.

The quantitative component consisted of expert ratings of each competency and performance indicator on a five-point Likert scale (1 = very low agreement, 5 = very high agreement) across four criteria: relevance, necessity, clarity, and measurability. These criteria were selected because they reflect the quality and practical utility of competency frameworks and are widely used in validation research. The ratings and feedback improved the framework after each of the 3 Delphi rounds, resulting in a holistic consensus-based expert process.

3.5. Data Collection and Analysis

Three rounds of Delphi were used to collect qualitative and quantitative data. In the qualitative section, experts commented in writing on the competency domains, component competencies, and performance indicators. Comments were analyzed using theme analysis. Responses were categorized similarly and grouped into common themes to assist in identifying concerns with organization, clarity, relevancy of the subject matter, integration of intelligent technologies, and how performance indicators may be monitored in the framework. The themes guided changes of the competency framework before each new Delphi round.

Quantitative data were collected using a structured Delphi questionnaire in Rounds 2 and 3. Means and standard deviations were calculated to reflect central tendency and consistency of expert evaluations. The percentage agreement was calculated as the proportion of experts who gave a rating of 4 or 5 on the five-point Likert scale.

Content validity was examined using the Item-level Content Validity Index (I-CVI) and the Scale-level Content Validity Index using the average method (S-CVI/Ave) (Polit & Beck, 2006). The I-CVI was calculated using simply the relevance criterion as recommended by Polit and Beck (2006). Scores of 4 ("highly relevant") and 5 ("very highly relevant") were considered content valid (score = 1), and scores below 4 were considered not content valid (score = 0). The I-CVI for each competency was the percentage of experts judging it as content valid. The S-CVI/Ave was the average of all I-CVI values across the framework. The updated kappa statistics were not employed because the expert panel comprised 20 professionals, which resulted in a very low possibility of random agreement as indicated by Polit and Beck (2006).

Expert consensus was derived from quantitative findings and qualitative comments. A competency was defined as consensus when all three predetermined criteria were met: mean score of 4.00 or above, 80% or above of the ratings of 4 or 5, and I-CVI of 0.78 or above, showing acceptable content validity (Hasson et al., 2000; Hsu & Sandford, 2007; Polit & Beck, 2006). Competencies that did not match these standards, or that were highlighted as problematic in the qualitative feedback, were changed, merged with related competencies, or deleted prior to the next Delphi cycle. Finally, a competency framework was considered to have good content validity when S-CVI/Ave was >0.90 (Polit & Beck, 2006).

The final interpretation of the Delphi results was based on quantitative data and qualitative feedback from experts. Therefore, the modifications were statistically consistent and also contained the professional opinions and recommendations of the expert panel.

3.6. Ethical Considerations

The study followed established ethical principles for educational research. Experts were informed of the study's purpose, the Delphi procedure, the voluntary nature of participation, and the intended use of their responses. Participation was based on informed consent. Experts' identities remained confidential during the Delphi rounds to maintain anonymity and minimize the influence of dominant individuals on group consensus. Data were used exclusively for research purposes and reported in aggregate form.

4. Results

4.1. Development of the Preliminary Competency Framework

The preliminary competency framework was created using the theoretical background from Section 2 and a review of literature on teacher competence, smart education, natural and social sciences education, competency-based teacher education, and the Vietnamese General Education Curriculum (MOET, 2018a). Instead of listing separate technological skills, the framework views Smart Natural and Social Sciences Teaching Competence as a combined professional ability that includes curriculum interpretation, pedagogical design, instructional implementation, assessment, and ongoing professional development.

Table 1. Preliminary competency domains and component competencies proposed for expert review.

Competency domain	Conceptual focus	Number of component competencies
Professional Knowledge for Smart Natural and Social Sciences Teaching	Professional knowledge underpins curriculum interpretation, subject content, learner characteristics, and Smart Education.	4
Smart Pedagogical Design	Planning inquiry-based, interdisciplinary, and technology-enhanced learning experiences.	4
Smart Teaching Implementation	Organizing and facilitating learning in authentic classroom contexts in smart natural and social sciences.	4
Smart Assessment and Learning Analytics	Using assessment evidence and learning analytics to support student learning and instructional decision-making.	3
Professional Reflection and Innovation	Reflecting on practice and continuously improving teaching through innovation and intelligent technologies.	3

Using this foundation, a preliminary competency framework was built with five competency domains, 19 component competencies, and their related performance indicators (see Table 1). This framework was an initial model based on the literature, not the final version. It was shared with the expert panel as a draft to allow for systematic review and improvement during the modified Delphi process.

At this point, the competency domains, component competencies, and performance indicators were all provisional. Experts were asked to review not just the relevance of each competency, but also how the domains relate to each other, whether the framework was complete, if the competency descriptions were appropriate, and if the performance indicators were suitable for assessment.

Table 1 presents the preliminary competency domains and their corresponding component competencies submitted for expert review. Table 1 shows the preliminary competency domains and their related component competencies that were given to experts for review in the first round of the Delphi process. The framework is expected to evolve through successive rounds of expert consultation. Consequently, the three-round Delphi process was designed to refine the framework progressively by integrating qualitative expert feedback with quantitative evidence of consensus. This process enabled the framework to move from an initial theoretical model to an expert-validated competency framework suitable for competency-based teacher education. The following sections describe how expert feedback informed the refinement of the framework across the three Delphi rounds.

4.2. Round 1: Conceptual Refinement of the Preliminary Competency Framework

The first Delphi round focused on refining the conceptual framework before the component competencies were evaluated quantitatively. At this stage, experts considered the framework mainly at the level of the five competency domains. They examined whether the proposed domains adequately represented the professional processes involved in smart natural and social sciences teaching and whether the meaning and scope of each domain were sufficiently clear.

The expert panel generally supported the five-domain structure. No new domain was proposed, and the five existing domains remained unchanged. However, the comments showed that the domains differed in the extent to which they required revision. The first domain, Professional Knowledge for Smart Natural and Social Sciences Teaching, was considered conceptually appropriate and remained largely unchanged. Experts agreed that this domain captured the knowledge base needed to interpret curriculum requirements, understand subject content and learner characteristics, and apply principles of smart education.

More extensive comments were made on the remaining four domains. The panel suggested that their meanings should be stated more clearly so that pedagogical design, instructional implementation, assessment, and professional reflection could be distinguished as related but separate professional processes. Experts also emphasized that the term "smart" should not simply indicate the use of digital tools. Instead, it should express the pedagogically informed use of intelligent technologies within each stage of teaching.

Analysis of the written comments produced four themes that guided the revision of the domains: conceptual differentiation, subject-specific orientation, pedagogical integration of Smart Education, and clarity of domain descriptions. These themes and the corresponding actions are summarized in Table 2.

Table 2. Main themes from Round 1 expert feedback and actions taken.

Theme	Main issue identified	Action taken after Round 1
Conceptual differentiation	The relationships among pedagogical design, teaching implementation, assessment, and professional reflection required clearer boundaries.	The scope and conceptual focus of Domains 2–5 were clarified to distinguish their functions within the teaching process.
Subject-specific orientation	Some domain descriptions remained too general and did not sufficiently reflect the characteristics of natural and social sciences teaching.	References to inquiry, interdisciplinary learning, authentic experience, evidence-based reasoning, and subject-specific teaching were strengthened.
Pedagogical integration of Smart Education	"Smart education" could be interpreted as technology use rather than as technology-informed professional practice.	Intelligent technologies, learning analytics, digital resources, and AI were positioned as resources supporting pedagogical decisions within each domain.
Clarity of domain descriptions	Several descriptions did not clearly communicate the intended meaning of the domains.	The wording and conceptual focus of the domains were refined before the component competencies were examined in Round 2.

The first theme concerned the relationship among the competency domains. Experts noted that designing learning activities, implementing instruction, assessing learning, and reflecting on teaching formed a connected professional process, but each domain needed a distinct focus. As a result, the scope of Domains 2–5 was clarified. “Smart pedagogical design” was defined around the planning of inquiry-based, interdisciplinary, and technology-enhanced learning experiences. Smart Teaching Implementation was distinguished as the enactment and facilitation of those experiences in authentic classroom contexts.

The assessment domain was also broadened conceptually. Experts thought that assessment was more than the design and use of assessment tasks. In smart education, feedback, instructional adjustment, and personalized support should also be informed by assessment evidence and learning data. The domain was therefore framed as Smart Assessment and Learning Analytics, emphasizing both assessment practice and the use of learning evidence in instructional decision-making.

Similar clarification was required for the final domain. Experts recommended that professional development should not be described only as the acquisition of additional knowledge or technical skills. It should include the review of teaching evidence, reflection on practice, pedagogical experimentation, and responsible innovation with emerging technologies. The domain was consequently framed as professional reflection and innovation.

The subject-specific meaning of the domains: The revision strengthened the subject-specific meaning of the domains. At the time of revision. Experts emphasized that Smart Natural and Social Sciences Teaching should retain the distinctive pedagogical features of this curriculum area, including scientific and social inquiry, interdisciplinary understanding, experiential learning, evidence-based reasoning, and engagement with authentic natural and social phenomena. These features the conceptual descriptions of the domains made them more explicit. The conceptual descriptions of the domains made these features more explicit.

Table 3 documents the outcome of Round 1 at the domain level. Because the labels shown in the preliminary and revised framework were largely retained, the main development concerned clarifying and expanding their conceptual meanings rather than wholesale renaming.

Table 3. Conceptual refinement of the competency domains following Round 1.

Competency domain	Round 1 decision	Conceptual refinement after expert consultation
1. Professional Knowledge for Smart Natural and Social Sciences Teaching	Retained	The domain was maintained because its focus on curriculum interpretation, disciplinary content, learner characteristics, and Smart Education principles was considered appropriate. Only minor clarification of wording was required.
2. Smart Pedagogical Design	Refined	The meaning of the domain was clarified around the design of inquiry-based, interdisciplinary, technology-enhanced, inclusive, and learner-centered learning experiences. The emphasis shifted from general lesson planning to pedagogical design suited to smart natural and social sciences teaching.
3. Smart Teaching Implementation	Reframed	The domain was distinguished from pedagogical design by focusing on the organization and facilitation of learning in authentic classroom contexts. Its meaning was expanded to include learner engagement, inquiry support, interaction, instructional adaptation, and the pedagogically appropriate use of AI and digital technologies.
4. Smart Assessment and Learning Analytics	Expanded	The domain was broadened from assessment practice to the collection, interpretation, and use of learning evidence. Learning analytics and intelligent assessment were incorporated to support feedback, instructional decisions, and personalized learning.
5. Professional Reflection and Innovation	Reframed	The domain was clarified as a process of evaluating teaching, reflecting on evidence, improving instructional practice, and engaging in responsible pedagogical innovation with digital technologies and AI.

Round 1 therefore resulted in refinement at the level of the competency domains rather than detailed validation of the individual component competencies. The five-domain structure was retained, but the meanings of Domains 2–5 were clarified and more closely aligned with the professional processes of smart natural and social sciences teaching. Domain 1 remained stable because experts considered its conceptual scope sufficiently clear.

The revised domain structure provided the conceptual basis for Round 2. In the second round, attention shifted from the overall framework to the detailed evaluation of the component competencies and their performance indicators in terms of relevance, necessity, clarity, and measurability.

4.3. Round 2: Quantitative Evaluation and Refinement of the Component Competencies

In Round 1, the competency domain concepts were conceptually refined. The second round evaluated the 19 preliminary component competencies that made up the first operational competency framework. The first round was used to develop the framework's conceptual structure, and the second round was used to validate the quality of the individual component competencies, checking their relevance, necessity, clarity of expression, and measurability for competency-based teacher education.

Each component competency was rated independently by experts on four pre-existing criteria, namely relevance, necessity, clarity, and measurability. Quantitative ratings were obtained on a five-point Likert scale, and qualitative comments were solicited concurrently to explain the ratings and recommend revisions where appropriate. This combination of quantitative assessment and qualitative feedback enabled the competency framework to be developed iteratively by consensus rather than by statistical agreement.

Descriptive statistics, including the mean score (M), standard deviation (SD), percentage agreement, and the Item-level Content Validity Index (I-CVI), were calculated according to the procedures described in Section 3. Consensus was considered achieved when a competency simultaneously satisfied the predefined criteria (mean ≥ 4.00, agreement ≥ 80%, and I-CVI ≥ 0.78). Table 4 summarizes the overall quantitative evaluation of Round 2 before the detailed competency-level analysis is presented.

Table 4. Overall quantitative evaluation of the revised competency framework during Round 2.

Evaluation indicator	Findings	Interpretation	Implication for the Delphi process
Expert participation	20 experts (100% response rate)	Full participation throughout Round 2	All expert responses included in the analysis
Mean ratings	4.18–4.55	High expert evaluation across all preliminary component competencies	Quantitative evidence supported retention of all competencies for further refinement.
Standard deviation	0.50–0.65	Low variability among expert ratings	Expert judgments were consistent across the panel.
Agreement	82–92%	All competencies exceeded the predefined consensus threshold (≥80%).	Consensus achieved for all preliminary component competencies
Item-level Content Validity Index (I-CVI)	≥0.82*	All competencies demonstrated acceptable content validity (≥0.78).	Content validity confirmed before Round 3
Qualitative feedback	Five major themes identified	Recommendations focused on improving competency orientation, reducing conceptual overlap, strengthening Smart Education integration, improving measurability, and enhancing instructional coherence.	Framework refined before the final Delphi round
Framework outcome	Preliminary framework refined from 19 to 18 component competencies	Refinement emphasized conceptual clarity and internal coherence rather than expanding competency coverage.	Revised framework submitted for final consensus in Round 3

Note: *The reported I-CVI values were ≥0.82; thus, all component competencies exceeded the predefined criterion of ≥0.78 for acceptable content validity.

The quantitative results are summarized in Table 4, and the expert panel consistently rated the revised competency framework very highly. All preliminary component competencies surpassed the predetermined consensus thresholds for mean ratings, agreement percentages, and content validity. Experts, therefore, agreed that the proposed competencies should be retained as a basis for further refinement. The qualitative comments that followed were thus more about enhancing conceptual precision, removing redundancy, and strengthening the practical applicability of the framework than about adding new competency areas.

4.4 Quantitative Evaluation of the Preliminary Component Competencies

Table 5 provides a detailed quantitative evaluation of each preliminary component competency. The mean scores were between 4.18 and 4.55, the standard deviations were between 0.50 and 0.65, and the percentages of agreement were between 82% and 92%, indicating high levels of agreement among the experts. All component competencies were consistent with the predetermined acceptance criteria, indicating content validity and justifying the inclusion of these competencies in the updated competency framework.

Table 5. Quantitative evaluation of the preliminary component competencies during Round 2.

Code	Component competency evaluated in Round 2	Mean	SD	Agreement (%)	I-CVI	Delphi decision	Revision following expert feedback	Relationship to the final competency framework
	Professional Knowledge for Smart Natural and Social Sciences Teaching							
1.1	Analyze learners' characteristics and learning needs for instructional planning	4.42	0.6	89	0.90	Retained with minor revision	The wording was clarified to connect learner characteristics and learning needs more directly with instructional planning.	Reformulated as 1.1 Analyze learners' characteristics and learning needs to inform instructional planning.
1.2	Analyze curriculum requirements and discipline-specific content	4.38	0.6	87	0.90	Retained with expansion	The competency was expanded to emphasize the use of curriculum and disciplinary analysis in constructing coherent learning experiences.	Expanded as 1.2 Analyze curriculum requirements and disciplinary content to design coherent learning experiences.
1.3	Apply Smart Education principles in Natural and Social Sciences teaching	4.35	0.6	86	0.90	Retained with clarification	The subject-specific purpose of applying Smart Education principles was made more explicit.	Clarified as 1.3 Apply principles of Smart Education to support subject-specific teaching and learning.
	Smart Pedagogical Design							
2.1	Design inquiry-based and interdisciplinary learning experiences	4.3	0.6	85	0.90	Retained with expansion	Scientific and social inquiry were explicitly incorporated to strengthen subject specificity.	Expanded as 2.1 Design inquiry-based and interdisciplinary learning experiences that promote scientific and social inquiry.
2.2	Design technology-enhanced learning activities	4.4	0.6	88	0.95	Retained with expansion	Active, collaborative, and personalized learning were added to clarify the pedagogical purposes of technology integration.	Expanded as 2.2 Design technology-enhanced learning activities that foster active, collaborative, and personalized learning.
2.3	Develop digital learning resources for Natural and Social Sciences teaching	4.55	0.5	92	1.00	Retained with refinement	The competency was refined to specify that digital resources should support inquiry, exploration, and authentic learning.	Refined as 2.3 Develop digital learning resources that support inquiry, exploration, and authentic learning experiences.
2.4	Organize flexible and technology-supported learning environments	4.32	0.6	86	0.90	Retained with expansion	Inclusion and student-centered learning were added to clarify the characteristics of a smart learning environment.	Expanded as 2.4 Organize smart learning environments that facilitate flexible, inclusive, and student-centered learning.
2.5	Extend global and community connections in learning activities	4.29	0.6	85	0.90	Integrated into related competencies	Experts considered global and community connections important but insufficiently distinct to remain a separate competency. Its content was incorporated into	Not retained as an independent competency; integrated mainly into 2.1–2.4.

Code	Component competency evaluated in Round 2	Mean	SD	Agreement (%)	I-CVI	Delphi decision	Revision following expert feedback	Relationship to the final competency framework
							interdisciplinary inquiry, authentic learning contexts, digital resources, and technology-enhanced activities.	
	Smart Instructional Implementation							
3.1	Facilitate inquiry-based and experiential learning activities	4.18	0.7	82	0.85	Retained with expansion	Problem-based learning was added, and the disciplinary context of Natural and Social Sciences was stated explicitly.	Expanded as 3.1 Facilitate inquiry-based, experiential, and problem-based learning activities in Natural and Social Sciences.
3.2	Integrate digital technologies into classroom instruction	4.25	0.6	84	0.90	Retained with expansion	AI and student engagement were added to clarify the professional purpose of technology integration.	Expanded as 3.2 Integrate digital technologies and AI to enhance classroom instruction and student engagement.
3.3	Guide students' inquiry, collaboration, and communication	4.34	0.6	86	0.90	Retained with clarification	Evidence-based reasoning was added to strengthen alignment with the epistemological features of Natural and Social Sciences.	Clarified as 3.3 Guide students in scientific inquiry, collaboration, communication, and evidence-based reasoning.
3.4	Adapt teaching according to learners' characteristics and classroom conditions	4.3	0.6	85	0.90	Retained with refinement	The basis for adaptation was specified more precisely as learners' progress, needs, and learning contexts.	Refined as 3.4: Adapt instructional strategies based on learners' progress, needs, and learning contexts.
	Smart Assessment and Learning Analytics							
4.1	Design formative and technology-supported assessment activities	4.28	0.6	84	0.90	Retained with expansion	The expression intelligent assessment was adopted, and support for continuous learning was made explicit.	Expanded as 4.1 Design formative and intelligent assessment activities that support continuous learning.
4.2	Collect and interpret evidence of student learning	4.27	0.6	84	0.90	Retained with clarification	The instructional purpose of collecting and interpreting evidence was explicitly added.	Clarified as 4.2 Collect and interpret evidence of student learning to inform instructional decisions.
4.3	Use learning data to monitor student progress and provide feedback	4.36	0.6	87	0.90	Retained with refinement	Learning data was specified as learning analytics, and feedback was refined as personalized feedback.	Refined as 4.3 Use learning analytics to monitor learning progress and provide personalized feedback.
4.4	Use assessment evidence to improve instruction	4.33	0.6	86	0.90	Retained with expansion	Learning analytics and the adjustment of instructional strategies were explicitly incorporated.	Expanded as 4.4 Adjust instructional strategies based on assessment evidence and learning analytics.
	Professional Reflection and Innovation							

Code	Component competency evaluated in Round 2	Mean	SD	Agreement (%)	I-CVI	Delphi decision	Revision following expert feedback	Relationship to the final competency framework
5.1	Reflect on and evaluate teaching effectiveness using learning evidence	4.31	0.6	85	0.90	Retained with expansion	Multiple sources of evidence and student learning data were added to strengthen evidence-informed professional reflection.	Expanded as 5.1 Evaluate teaching effectiveness using multiple sources of evidence and student learning data.
5.2	Improve teaching through research and pedagogical innovation	4.28	0.6	84	0.90	Retained with reformulation	The research-oriented wording was reframed around instructional improvement, pedagogical innovation, and emerging technologies.	Reformulated as 5.2 Improve instructional practices through pedagogical innovation and emerging technologies.
5.3	Use digital technologies safely, responsibly, and ethically	4.26	0.6	83	0.85	Retained with expansion	Sustainability and the ethical use of AI were added to reflect emerging professional responsibilities.	Expanded as 5.3 Demonstrate ethical, responsible, and sustainable use of digital technologies and AI in teaching.

Note: Agreement (%) represents the proportion of experts assigning ratings of 4 or 5. I-CVI values were derived from the relevance evaluation. Consensus was considered achieved when all predefined criteria (Mean ≥ 4.00, Agreement ≥ 80%, and I-CVI ≥ 0.78) were satisfied.

Table 5 confirms that all nineteen component competencies met the predefined quantitative consensus criteria. Mean ratings ranged from 4.18–4.55, standard deviations ranged from 0.50–0.65, and agreement percentages ranged from 82%–92%. Results showed that the expert panel agreed on the substantial relevance of all competencies within the Round 2 framework. The experts did not, however, agree that each statement should be left unaltered. In the written comments, differences in conceptual precision, scope, and measurability were identified, which had to be addressed before the final consensus round.

The highest score was obtained in the development of digital learning resources for teaching natural and social sciences (M = 4.55, SD = 0.50, agreement = 92%). Although experts agreed that this competency should be retained, they recommended specifying the pedagogical functions of digital resources. Thus, the revised statement reinforced their use as supports for inquiry, exploration, and authentic learning experiences and not just for the production of digital materials.

The lowest mean rating was recorded for Facilitate inquiry-based and experiential learning activities (M = 4.18, SD = 0.65, agreement = 82%). Although the competency exceeded the consensus thresholds, experts recommended extending its scope to include problem-based learning and stating the natural and social sciences context more explicitly. The revised wording consequently provided a clearer account of the professional performance expected during instructional implementation.

The only component competency not retained as an independent statement was extending global and community connections in learning activities. Expert comments did not question the educational value of global and community connections. Instead, they indicated that this content overlapped with interdisciplinary inquiry, authentic learning contexts, digital-resource development, and technology-enhanced learning activities. Its substantive elements were therefore integrated across the remaining competencies of Smart Pedagogical Design. This treatment reduced the framework from nineteen to eighteen component competencies without removing the underlying educational content.

The remaining changes involved clarification, expansion, and reformulation. Competencies concerning professional knowledge were refined to connect learner and curriculum analysis more directly with instructional planning. The Smart Pedagogical Design was enhanced by more explicit references to scientific and social inquiry, active learning, collaboration, personalization, inclusion, and authentic learning. The instructional implementation competencies were expanded to include AI-supported teaching, evidence-based reasoning, and adaptation to learners' progress and needs. Assessment competencies were sharpened through intelligent assessment, learning analytics, personalized feedback, and evidence-informed instructional adjustment. Professional Reflection and Innovation were also clarified around evidence-based evaluation, pedagogical innovation, and ethical, responsible, and sustainable technology use.

These item-level decisions were subsequently grouped into five recurring themes, as presented in Table 6.

Table 6. Summary of expert feedback and revisions following Round 2.

Theme identified from expert feedback	**Issues identified by experts**	**Revisions undertaken**	**Contribution to the revised framework**
Strengthening competency orientation	Several statements described knowledge areas or general teaching activities rather than observable professional performance.	Competency statements were rewritten using action-oriented language linked to instructional planning, design, implementation, assessment, and reflection.	Improved alignment with competency-based teacher education and made the competencies more observable and assessable.
Strengthening subject-specific relevance	Some statements did not sufficiently represent the distinctive pedagogical characteristics of Natural and Social Sciences teaching.	Scientific and social inquiry, interdisciplinary learning, experiential and problem-based learning, authentic contexts, and evidence-based reasoning were made more explicit.	Strengthened the subject-specific identity of the framework.
Integrating Smart Education across professional practice	Digital technologies were sometimes represented as separate technical capabilities rather than resources embedded in teaching practice.	AI, digital resources, smart learning environments, intelligent assessment, and learning analytics were integrated across pedagogical design, instructional implementation, assessment, and professional reflection.	Shifted the framework from isolated technology use toward pedagogically meaningful integration of intelligent technologies.
Reducing conceptual overlap and improving coherence	Some competencies covered related content, particularly within Smart Pedagogical Design.	Overlapping content was redistributed or integrated. Global and community connections were incorporated into interdisciplinary inquiry, authentic contexts, digital resources, and technology-enhanced learning rather than retained separately.	The framework was reduced from 19 to 18 component competencies while preserving its substantive coverage.
Improving clarity and measurability	Several competencies and performance indicators were considered too broad or insufficiently precise for consistent interpretation and assessment.	Wording was refined to specify observable actions, instructional purposes, sources of evidence, and expected professional decisions.	Increased operational clarity and suitability for curriculum development and competency-based assessment.

4.5. Outcome of Round 2

Round 2 confirmed that the five-domain structure established after Round 1 was sufficiently stable to proceed to final validation. Experts did not recommend adding or removing any competency domain. Their comments instead focused on the wording, scope, internal relationships, and operational clarity of the component competencies and associated performance indicators.

The quantitative results supported all nineteen competency areas, while the qualitative feedback determined how those areas should be represented in the revised framework. Eighteen component competencies were retained through clarification, expansion, or reformulation. One competency, Extend global and community connections in learning activities was integrated into related competencies rather than maintained as a separate statement. The revised framework therefore comprised five competency domains and eighteen component competencies.

More importantly, the Round 2 revisions strengthened the framework's conceptual orientation. The competencies became more explicitly connected to observable professional practice, subject-specific inquiry, intelligent technology integration, evidence-informed assessment, and continuous professional improvement. The revised framework was subsequently circulated to the same expert panel in Round 3, together with a summary of the changes made, for final confirmation of consensus and content validity.

4.6. Round 3. Finalization of Expert Consensus

The third Delphi round was conducted to evaluate whether the changes made after Round 2 were sufficient to meet the experts' recommendations and whether the revised competency framework reached a stable consensus level for final adoption. The third round was mainly a validation stage, compared with the previous round, which focused on refining the competency structure and individual component competencies. In this round, the experts validated the revised framework as a coherent and integrated competency system.

Before completing the Round 3 questionnaire, all experts received three documents: (1) the revised competency framework comprising five competency domains and eighteen component competencies, (2) a summary of the quantitative and qualitative findings from Round 2, and (3) a revision report explaining how each recommendation from Round 2 had been incorporated into the revised competency statements and performance indicators. This procedure enabled experts to evaluate not only the revised framework itself but also the appropriateness of the revisions made following the previous Delphi round.

For methodological consistency, we maintained the same evaluation criteria as in Round 2. Each component competency was assessed by experts for its relevance, necessity, clarity and measurability. Mean ratings, standard deviations, agreement percentages, Item-level Content Validity Indices (I-CVI), and the Scale-level Content Validity Index using the average method (S-CVI/Ave) were computed following the procedures outlined in the methodology. For content validity analysis, only the relevance ratings were used to calculate I-CVI and S-CVI/Ave.

Table 7. Final quantitative evaluation of the revised competency framework during Round 3.

Evaluation indicator	Result	Interpretation	Decision
Number of experts	20	All experts completed Round 3	Included in the final analysis
Mean rating	4.42–4.76	Very high evaluation of the revised framework	Final framework retained
Standard deviation	0.42–0.58	High consistency among expert ratings	Framework considered stable
Agreement percentage	90–100%	Consensus strengthened after Round 2	Final consensus achieved
I-CVI	0.90–1.00	Excellent item-level content validity	All competencies retained
S-CVI/Ave	0.96	Excellent scale-level content validity	Content validity confirmed
Qualitative feedback	Minor editorial refinements	No substantive conceptual revisions required	Framework finalized

4.7. Round 3 Results Interpretation

Table 7 shows the results demonstrating that the revised competency framework received a high and consistent level of consensus from experts. Mean ratings ranged from 4.42 to 4.76, standard deviations were between 0.42 and 0.58, and the percentage of agreement increased to 90–100%, indicating a higher consensus than in Round 2. The results show that the modifications made after Round 2 were effective in solving the problems found in the previous step of the Delphi process.

Content validity analysis also validated the quality of the revised framework. All 18 component competencies had an Item-level Content Validity Index (I-CVI) between 0.90 and 1.00, indicating excellent content validity at the individual competency level. The overall Scale-level Content Validity Index (S-CVI/Ave) of 0.96 also exceeded the recommended criterion for newly developed competency frameworks, indicating excellent content validity of the framework as a whole.

Qualitative comments received during Round 3 were very different from those received in Round 2. Instead of suggesting conceptual changes, the experts generally agreed that the revised competency framework adequately captured the professional competencies needed for Smart Natural and Social Sciences Teaching. The other recommendations were minor editorial improvements, including improving the consistency of terminology, simplifying several competency statements, and refining the wording of selected performance indicators. None of these comments required modification of the competency domains, the component competencies, or their overall organizational structure.

Taken together, the quantitative and qualitative findings indicate that the revised competency framework had reached a stable level of expert consensus and required no further conceptual revision.

4.8. Final Validation of the Competency Framework and Performance Indicators

Beyond confirming the five competency domains and eighteen component competencies, the expert panel also completed the final validation of the associated 112 performance indicators. Following the Round 2 conceptual refinements, each performance indicator was reviewed for consistency with the revised competency statements, conceptual clarity and appropriateness for competency-based assessment.

The final review confirmed that the performance indicators adequately represented observable professional behaviors associated with each component competency. Minor editorial refinements were introduced to improve wording consistency and eliminate redundancy; however, experts did not recommend adding, deleting, or restructuring any performance indicators. Consequently, the final framework comprised five competency domains, eighteen component competencies, and 112 validated performance indicators, all of which were supported by strong expert consensus.

Because presenting the complete set of performance indicators within the main manuscript would substantially reduce readability, Table 8 presents the validated competency domains and component competencies, whereas the complete list of the 112 validated performance indicators is provided in Supplementary Appendix A.

4.9. Final Competency Framework

The completion of Round 3 marked the conclusion of the modified Delphi process. The resulting competency framework represents the validated outcome of three iterative rounds of expert consultation involving specialists in primary education, science education, educational technology, curriculum development, and educational measurement. Throughout the Delphi process, the framework evolved from a literature-derived preliminary model into an empirically validated competency framework supported by quantitative evidence and expert consensus.

As presented in Table 8, the final framework comprises five competency domains and eighteen component competencies organized to reflect the professional teaching process in Smart Natural and Social Sciences Teaching. The framework begins with Professional Knowledge for Smart Natural and Social Sciences Teaching, which establishes the disciplinary, curricular, learner-related, and Smart Education knowledge required for professional practice. This foundation is followed by Smart Pedagogical Design, which focuses on designing inquiry-based, interdisciplinary, technology-enhanced, and learner-centered learning experiences. The third domain, Smart Instructional Implementation, emphasizes facilitating inquiry learning through adaptive instructional strategies and the meaningful integration of digital technologies and artificial intelligence. The fourth domain, Smart Assessment and Learning Analytics, highlights formative assessment, learning analytics, evidence-informed instructional adjustment, and personalized feedback. Finally, Professional Reflection and Innovation emphasizes evidence-based reflection, continuous professional improvement, pedagogical innovation, and the ethical, responsible, and sustainable use of digital technologies and artificial intelligence.

Collectively, the eighteen component competencies are operationalized through 112 validated performance indicators, which translate each competency into observable professional behaviors. These indicators specify expected instructional actions, pedagogical decisions, assessment practices, technology integration, and reflective professional performance, thereby enabling the framework to support curriculum development, competency-based assessment, teaching practicum evaluation, and future empirical validation.

The complete validated competency framework is presented in Table 8, whereas the full set of validated performance indicators is provided in Supplementary Appendix A.

Table 8. Final validated competency framework for smart natural and social science teaching.

Competency Domain	Component Competencies
1. Professional knowledge for smart natural and social science teaching	1.1 Analyze learners' characteristics and learning needs to inform instructional planning. 1.2 Analyze curriculum requirements and disciplinary content to design coherent learning experiences. 1.3 Apply principles of smart education to support subject-specific teaching and learning.
2. Smart pedagogical design	2.1 Design inquiry-based and interdisciplinary learning experiences that promote scientific and social inquiry. 2.2 Design technology-enhanced learning activities that foster active, collaborative, and personalized learning. 2.3 Develop digital learning resources that support inquiry, exploration, and authentic learning experiences. 2.4 Organize smart learning environments that facilitate flexible, inclusive, and student-centered learning.
3. Smart instructional implementation	3.1 Facilitate inquiry-based, experiential, and problem-based learning activities in natural and social sciences. 3.2 Integrate digital technologies and AI to enhance classroom instruction and student engagement. 3.3 Guide students in scientific inquiry, collaboration, communication, and evidence-based reasoning. 3.4 Adapt instructional strategies based on learners' progress, needs, and learning contexts.
4. Smart assessment and learning analytics	4.1 Design formative and intelligent assessment activities that support continuous learning. 4.2 Collect and interpret evidence of student learning to inform instructional decisions. 4.3 Use learning analytics to monitor learning progress and provide personalized feedback. 4.4 Adjust instructional strategies based on assessment evidence and learning analytics.
5. Professional reflection and innovation	5.1 Evaluate teaching effectiveness using multiple sources of evidence and student learning data. 5.2 Improve instructional practices through pedagogical innovation and emerging technologies. 5.3 Demonstrate ethical, responsible, and sustainable use of digital technologies and AI in teaching.

The validated competency framework constitutes the principal outcome of this study. Rather than merely identifying the competencies required for smart natural and social sciences teaching, the framework provides an operational structure comprising five competency domains, eighteen component competencies, and 112 validated performance indicators. The integration of competency domains, component competencies, and observable performance indicators enables the framework to function as both a conceptual model and a practical reference for competency-based curriculum design, professional learning, teaching practicum supervision, competency assessment, and future empirical validation within primary teacher education.

5. Discussion

This study contributes to teacher competence research in smart education by reconceptualizing smart teaching competence as a subject-specific professional capability, rather than as mere extensions of generic digital competence. Existing frameworks such as PCK, TPCK, DigCompEdu and the UNESCO AI Competency Framework for Teachers extend teacher competence through the integration of disciplinary knowledge, pedagogy, digital competence and AI. However, these frameworks were developed for a variety of instructional contexts and offer little guidance in defining competency expectations in specific disciplines. The results show that generic digital competence cannot fully understand Smart Education. Competence should be conceptualized in relation to the professional practices which characterize individual curriculum areas. Thus, the study demonstrates that smart teaching competence is subject-dependent and should be understood through the subject-specific pedagogical processes.

This disciplinary perspective is particularly important in the education of natural and social sciences. In these fields, students are guided in processes of teaching inquiry, observation, investigation, interpretation of evidence, interdisciplinary reasoning and exploration of authentic phenomena (Bybee, 2019; Magnusson et al., 1999; National Research Council, 2012). Intelligent technologies, on the other hand, supplement the existing pedagogical processes without imposing new pedagogical purposes (Novak & Treagust, 2022). The validated competency framework integrates smart education into the real practices of natural and social sciences teaching through joint curriculum analysis, inquiry-oriented lesson design, instructional implementation, formative assessment, and reflective improvement into one integrated competency structure. This approach operationalizes smart education as discipline-based pedagogy instead of technology adoption (Liu, Rogat, & Bertling, 2013).

Theoretically, this study contributes to the redefinition of the role of intelligent technologies in teachers' competence. Digital competence and AI are often mentioned as core teacher competences in international frameworks (OECD, 2021; Redecker, 2017; UNESCO, 2024). While these frameworks are useful in informing policy and teacher education, they are limited in their focus on what teachers should know and be able to do in their implementation of technology (D'Mello, 2021). On the other hand, the validated framework developed in this study embeds intelligent technologies into the professional processes of teaching. The pedagogical tools of curriculum interpretation, instructional design, evidence-informed decision-making, personalized assessment and professional reflection are conceptualized as being supported through the use of AI, learning analytics, intelligent assessment and digital learning resources. The educational value of such tools depends not only on their technical sophistication but also on their potential impact on pedagogical judgment in real-life teaching situations (Caspari-Sadeghi, 2023). Such a view aligns with recent studies showing that the effects of generative AI depend largely on teachers' pedagogical integration of AI, rather than on technical proficiency alone (Carrión Candel et al., 2026; Tang & Zhong, 2026; Vivas-Urias et al., 2026).

The validated competency framework has major implications for primary teacher education. Many teacher education programs still break professional preparation into its component parts (e.g., disciplinary knowledge, teaching methodology, educational technology, assessment). The findings suggest that this compartmentalization may no longer be sufficient to prepare future teachers for Smart Education (Brown et al., 2026). Therefore, intelligent technologies should be embedded in all subject-specific teacher education to develop pre-service teachers' competencies in curriculum interpretation, inquiry-oriented lesson design, adaptive instruction, formative assessment, learning analytics, and evidence-informed professional reflection as intertwined aspects of professional practice. This integrated approach is more likely to prepare future teachers for complex technology-rich learning environments, while maintaining the pedagogical integrity of natural and social science education (Ramnarain, 2026).

This study presents not only theoretical and practical contributions, but also highlights the methodological value of the Delphi technique in developing competency frameworks. The three-round Delphi process is not only a consensus-building process but also a systematic process for translating broad theoretical perspectives into a coherent and measurable competency framework. Through iterative quantitative assessments and consensus validation, Smart Education, teacher competence, and subject-specific pedagogy were translated into specific competency domains, constituent competencies, and measurable performance indicators (Yaccob, Yunus, & Hashim, 2024). This methodological approach is a useful reference for future research on competency models in rapidly digitalizing disciplines.

Together, the results suggest that Smart Natural and Social Sciences Teaching Competence is a subject-specific professional competence and not an add-on to existing teacher competence models based on digital competence. Curriculum analysis, teaching design, teaching delivery, evaluation, and reflective practice all incorporate smart technologies deliberately. The validated framework, therefore, offers a theoretically grounded and operationally validated foundation for competency-based teacher education, curriculum development, and future research in Smart Education.

6. Conclusion

A competency framework for smart natural and social sciences teaching for pre-service primary teachers was developed and validated using a three-round Delphi process. The resulting framework consists of five competency domains, 18 component competencies, and performance indicators. This framework provides a structured representation of professional competencies required for teaching natural and social sciences in smart education environments.

The results indicate that smart teaching competence can best be understood through the professional processes of teaching. The proposed framework is organized around curriculum analysis, pedagogical design, instructional implementation, assessment, and professional reflection. Intelligent technologies are embedded throughout these processes and not treated as separate competencies. This approach is based on existing competency frameworks and allows for a subject-specific understanding of smart education that corresponds to the pedagogical features of natural and social sciences.

The framework serves as a reference for hands-on teacher education, enabling curriculum design, competency-based assessment, and the design of learning experiences involving intelligent technologies and subject-specific pedagogy. The Delphi process also provides a systematic way to build theoretically sound, expert-validated competency frameworks.

There are a few limitations to keep in mind. The framework was created by expert consensus and offers evidence of content validity but not educational effectiveness. The expert panel was drawn from the Vietnamese teacher education context, and the framework has not been implemented or evaluated with pre-service primary teachers. These factors should be kept in mind in interpreting and applying the results.

Future research should explore the construct validity of the framework and its effectiveness in teacher education programs. Empirical investigations should be carried out to explore the development of the suggested competencies during teacher training and their impact on the quality of education in smart natural and social science classrooms. Comparative research across curriculum areas would further clarify which competencies are universal to Smart Education and which are discipline-specific. Such evidence would provide an empirical basis for competency-oriented teacher education in digitally transformed educational settings.

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Supplementary Appendix A. Representative Performance Indicators for the Validated Competency Framework

This appendix summarizes the operational structure of the validated competency framework developed through the three-round modified Delphi process. The final framework comprises five competency domains, eighteen component competencies, and 112 validated performance indicators. To maintain the readability of the main manuscript, only representative performance indicators are presented. These examples illustrate the observable professional behaviors associated with each component competency and demonstrate how the competency framework can be translated into measurable professional practice.

Domain 1. Professional Knowledge for Smart Natural and Social Sciences Teaching

Component Competency 1.1: Analyze learner characteristics and needs to guide instructional planning.

PI1.1.1 Is aware of learners' prior knowledge related to Natural and Social Sciences before instruction.

PI1.1.2 Recognizes learners' misconceptions and potential learning difficulties.

PI1.1.3 Analyzes the developmental characteristics, interests, and learning needs of learners.

PI1.1.4 Analyzes data about learners to set appropriate learning goals.

PI1.1.5 Selects teaching methods and learning activities based on evidence of learner performance.

PI1.1.6 Modifies instructional planning to accommodate diverse learners and learning needs.

Component Competency 1.2: Design of coherent learning experiences based on analysis of curriculum requirements and discipline content

PI1.2.1 Demonstrates clear understanding of curriculum requirements and desired learning outcomes.

PI1.2.2 Recognizes important concepts, knowledge in disciplines, and interconnections in natural and social sciences.

PI1.2.3 Examines the development of curriculum content across grade levels.

PI1.2.4 Connects disciplinary knowledge to real-world situations that are authentic.

PI1.2.5 Chooses important content that is appropriate to learners' characteristics and curriculum expectations.

PI1.2.6 Uses curriculum analysis to build a cohesive lesson plan and instructional sequence.

Component Competency 1.3 Application of principles of Smart Education to support subject-specific teaching & learning

PI1.3.1 Explains fundamental principles of Smart Education in teaching Natural and Social Science.

PI1.3.2 Uses digital technology to accomplish instructional goals.

PI1.3.3 Designs learning activities based on the principles of Smart Education

PI1.3.4 Uses digital technology to improve inquiry-based and learner-centered teaching.

PI1.3.5 Evaluates the pedagogical suitability of technology use in specific teaching situations.

PI1.3.6 Uses educational technologies appropriately and ethically in instructional planning.

Domain 2. Smart Pedagogical Design

Component Competency 2.1: Design inquiry-based and interdisciplinary learning experiences.

PI2.1.1 Identifies opportunities for authentic inquiry in Natural and Social Sciences through analysis of curriculum requirements.

PI2.1.2 Plans inquiry tasks for students to engage in scientific investigations and use of evidence.

PI2.1.3 Integrates knowledge of Natural and Social Sciences, and other relevant disciplines in the planning of learning activities.

PI2.1.4 Relates learning activities to real-life issues and local situations.
PI2.1.5 Supports collaborative learning activities that promote student participation.
PI2.1.6 Aligns inquiry activities with desired learning outcomes and competency development.
PI2.1.7. Enhances inquiry lesson plans with regard to pedagogy and learners' needs.
Component Competency 2.2: Designing learning activities with technology
PI2.2.1 Selects digital technologies to support lesson goals and learner characteristics.
PI2.2.2 Develops learning activities that make use of digital technologies to support active learning.
PI2.2.3 Appropriately integrates artificial intelligence tools into instructional activities.
PI2.2.4 Designs collaborative digital learning experiences that require interaction and communication
PI2.2.5 Uses digital technologies to adapt learning activities to the diversity of learners.
PI2.2.6 Designs technology-enriched learning with accessibility, inclusiveness, and digital safety as the core.
PI 2.2.7 Evaluates the suitability of chosen digital technologies for teaching purposes before their implementation.
Component Competency 2.3: Development of digital learning resources that encourage inquiry and authentic learning
PI2.3.1 Develops digital learning resources aligned to curriculum requirements and learning outcomes.
PI2.3.2 Prepares interactive digital media to facilitate inquiry learning.
PI2.3.3 Designs multimedia resources to suit developmental characteristics of learners.
PI2.3.4 Employs genuine learning resources from scientific and community contexts.
PI2.3.5 Adapts digital learning resources to meet the needs of diverse learners.
PI2.3.6 Assesses the quality, usability and educational value of digital learning resources.
PI2.3.7 Updates digital learning resources according to feedback from learners and instructional evaluation.
Component Competency 2.4: Develop smart learning environments for flexible, inclusive and learner-centered learning
PI2.4.1 Develops adaptable student-centered learning environments.
PI2.4.2 Develops digital platforms and classroom resources for learner engagement
PI2.4.3 Provides inclusive learning conditions adapted to the diversity of learners.
PI2.4.4 Provides opportunities for collaboration in face-to-face and digital learning environments.
PI2.4.5 Uses physical, digital and community resources effectively in learning.
PI2.4.6 Identifies possible obstacles to participation in smart learning environments and develops plans to overcome them.
PI2.4.7 Uses analysis of learner engagement and teaching effectiveness to enhance learning environments.
Domain 3. Smart Instructional Delivery
Component Competency 3.1 Facilitate inquiry-based, experiential and problem-based learning activities
PI3.1.1 Fosters inquiry-based learning through questioning, exploring, and investigating.
PI3.1.2 Enables learners to use appropriate learning strategies to conduct scientific and social inquiry.
PI3.1.3 Engages students in experiential and problem-basedlearning that encourages active student involvement.
PI3.1.4 Enables the development of evidence-based explanations from learning experiences.
PI3.1.5 Promotes students' collaborative learning through discussion, teamwork and interaction with peers.
PI3.1.6 Assesses learner engagement and adapts facilitation approaches for active engagement.
Component Competency 3.2: Digital technologies and AI in the teaching classroom
PI3.2.1 Intentionally uses digital technologies to improve teaching practice.
PI3.2.2 Makes effective use of AI tools in enhancing learning activities.
PI3.2.3 Uses digital learning platforms and communication tools to facilitate social interaction among learners.
PI3.2.4 Uses digital technology to facilitate inquiry, collaboration, and problem solving
PI3.2.5 Responds appropriately to technical and instructional difficulties in technology-enhanced instruction.
PI3.2.6 Maintains responsible, ethical, and safe use of digital technologies in instruction.
Component Competency 3.3 Facilitates student inquiry, collaboration, communication and evidence-based reasoning
PI3.3.1 Facilitates learners' questioning and problem-solving of authentic problems.
PI3.3.2 Assists learners to collect, analyze and interpret evidence.
PI3.3.3 Encourages scientific discussion and knowledge construction.
PI3.3.4 Helps learners to express scientific ideas with relevant evidence.
PI3.3.5 Fosters critical thinking and evidence-based reasoning in all learning experiences.
3.3.6 Provides prompt and pertinent guidance to promote learner independence and collaborative inquiry.
Component Competency 3.4: Expertise in the component: Changing instructional strategy as learners mature and the context of learning changes
PI3.4.1 Ongoing assessment of student learning during instruction.
PI3.4.2 Modifies instructional techniques based on learner response and involvement
PI3.4.3 Data guides instructional decisions related to student needs and learning progress.
PI3.4.4 Adapts instruction to individual needs of learners.
PI3.4.5. Manages unforeseen instructional events by considering the learning objectives.
PI3.4.6 Shows how to increase the impact of teaching in delivering lessons.
Domain 4: Intelligent Assessment and Learning Analytics
Component Competency 4.1: Plans intelligent and formative assessment activities
PI4.1.1 Designs tasks for formative assessment in line with the intended learning outcomes.
PI4.1.2 Designs assessment activities that measure learner competencies based on authentic learning tasks.
PI4.1.3 Uses digital assessment tools appropriately in the learning and teaching process
PI4.1.4 Plans for assessment of designs to give learners continuous feedback.
PI4.1.5 Uses self-assessment and peer-assessment techniques in classroom assessment.
PI4.1.6 Promotes fairness, inclusiveness and transparency in the design of assessment.

Component Competency 4.2: Collect and assess evidence of student learning
PI4.2.1 Collects data on learning from different assessment tools and sources.
PI4.2.2 Evaluates the learner's performance against set assessment criteria.
PI4.2.3Analyzes data to identify students' strengths and learning needs.
PI4.2.4 Evidence of assessment is used to monitor progress of individuals and groups in learning
PI4.2.5 Systematically collects evidence of assessment to guide instructional decision-making.
PI4.2.6 Ensures assessment evidence is valid and consistent before making professional judgments.
Component Competency 4.3: Learning analytics for progress monitoring and individualized feedback
PI4.3.1 Uses learning analytics to monitor learner engagement and learning progress
PI4.3.2 Uses data on learning from digital learning platforms
PI4.3.3 Employs learning analytics to pinpoint learners who need additional instructional support.
PI4.3.4 Provides timely, constructive, and personalized feedback to students based on evidence of student learning.
PI4.3.5 Uses learning analytics data to guide differentiated instruction.
PI4.3.6 Evaluates the role of feedback in the learner's development.
Component Competency 4.4: Adjust teaching approaches in light of assessment information and learning analytics
PI4.4.1 Uses data from assessments to guide instruction.
PI4.4.2 Adapts learning activities according to learners' development and assessment results.
PI4.4.3 Uses evidence to inform instructional decisions during the teaching process.
PI4.4.4 Adapts the presentation of lessons to learning analytics and evidence from the classroom.
PI4.4.5 Uses assessment data to inform future instruction.
PI4.4.6 Uses assessment data and student progress to assess the impact of instructional accommodations.
Domain 5: Reflection and Innovation
Component Competency 5.1: Take a view on the effectiveness of teaching from a range of evidence
PI5.1.1 Critically reflects on teaching practice using evidence from teaching and learning activities.
PI5.1.2 Uses student performance, classroom observations and assessment data to determine effectiveness of instruction.
PI5.1.3 Systematic self-evaluation as a means to identify strengths and weaknesses.
PI5.1.4. Uses learner and colleague feedback to improve teaching.
PI5.1.5 Professional reflections that inform continuous improvement of teaching are documented.
PI5.1.6 Uses reflective evidence to plan future instruction.
Component Competency 5.2: Use pedagogical innovation and new technologies to improve teaching practices
PI5.2.1 Uses results of educational research to enhance teaching practices.
PI5.2.2 Explores innovative pedagogical approaches related to Smart Education
PI5.2.3 Uses new digital technologies to improve teaching and learning.
PI5.2.4 Develops new teaching strategies based on evidence from education and the needs of learners.
PI5.2.5 Work with colleagues to share new teaching practices and professional experiences.
PI5.2.6 Assess the consequences of pedagogical innovations on continuous professional development.
Competency Component 5.3: The ethical, responsible and sustainable use of digital technologies and artificial intelligence
PI5.3.1 Uses digital technologies and artificial intelligence responsibly in professional practice.
PI5.3.2 Safeguards the privacy of learners, personal data and digital safety in all teaching activities.
PI5.3.3 Advocates, models, and teaches safe, legal, and ethical use of digital information and technology.
PI5.3.4 Critically analyses the potential and limitations of new technologies for education.
PI5.3.5 Demonstrates professional responsibility in the selection and use of tools based on artificial intelligence.
PI5.3.6 Shows commitment to continuing professional learning in response to technological and educational change.