



Vol. 15 No. 3 (2026): June

<http://dx.doi.org/10.33578/jpkip.v15i3.711-728>

Ecosystem-based IPAS modules: traces of innovation by pre-service elementary school teachers in 21st-century learning

Jeane Kalengkongan   ^{1*}, Deane Umboh  ¹

¹ Manado State University, Minahasa, Indonesia, 95445

Article info	Abstract
Keywords: ecosystem education, IPAS module, pedagogical competence, pre- service teachers, project-based learning,	This study examines how pre-service elementary teachers develop pedagogical competence through a project-based learning experience involving the design of ecosystem-based <i>IPAS</i> (integrated science and social studies) modules. The study aims to explore (1) the instructional design process, (2) the characteristics and quality of the modules produced, and (3) participants' perceptions of their pedagogical competence development. A qualitative case study design was employed involving 30 pre-service teachers enrolled in a primary teacher education program. Data were collected through classroom observations, document analysis of instructional modules, and semi-structured interviews, and were analyzed thematically. Module quality was further examined using expert validation criteria. The findings indicate that pre-service teachers demonstrated emerging pedagogical competence, particularly in aligning content with learning objectives and adapting instructional materials to students' characteristics. The modules produced demonstrate satisfactory content and instructional quality, while technical components, such as organization and visual presentation, were less consistent. Interview data suggest that the project supported reflective engagement with teaching practices, although participants reported challenges in simplifying scientific concepts and using digital tools effectively. This study contributes to the literature by providing an empirical account of how project-based learning supports the development of pedagogical competence in integrated science instruction. It highlights the importance of combining authentic design tasks with structured pedagogical and technical support in teacher education programs.

* Corresponding Author.

E-mail address: jeanekalengkongan@unima.ac.id (Jeane Kalengkongan)

DOI: <http://dx.doi.org/10.33578/jpkip.v15i3.711-728>

Received 16 February 2026; Received in revised form 11 May 2026; Accepted 24 May 2026

Available online 30 June 2026

e-ISSN 2598-5949 | p-ISSN 2303-1514 © The Authors.

1. Introduction

High-quality education is widely recognized as a fundamental foundation for national development, as it directly contributes to the quality of human resources and future societal progress (Akintayo et al., 2024; Wang et al., 2024). Within this context, elementary school teachers hold a strategic role in establishing students' foundational knowledge and learning dispositions. This responsibility becomes particularly essential in integrated subjects such as integrated science and social studies (*IPAS*), which combine science and social studies through interdisciplinary and contextual learning experiences.

In elementary education, effective *IPAS* instruction requires teachers to possess strong pedagogical competence, particularly in designing learning experiences that connect academic concepts with students' real-life environments. Pedagogical competence includes understanding learners' characteristics, designing meaningful instruction, facilitating active learning, and evaluating student outcomes (Geletu, 2022). For pre-service elementary teachers, these competencies should be developed systematically during teacher education, especially through authentic tasks that bridge theoretical knowledge and classroom practice.

One essential aspect of this competence is the ability to design contextual learning modules based on ecosystem themes. Ecosystem-based *IPAS* modules are pedagogically significant because they integrate scientific concepts, environmental awareness, and social realities closely related to students' daily experiences. Such modules support meaningful learning while fostering critical thinking and environmental literacy (Kellogg et al., 2024).

However, previous studies consistently indicate that pre-service elementary teachers often struggle to translate contextual learning principles into systematically designed instructional modules. Recent evidence reveals that pre-service teachers frequently struggle to align learning objectives, instructional activities, and assessment components in coherent teaching modules, despite having adequate theoretical understanding of pedagogical concepts (Purnomo et al., 2024). Research by Tsybulsky and Muchnik (2021) further provides an essential framework for understanding how competencies can be developed through the design of authentic and multidisciplinary project-based science learning experiences. Their findings suggest that active involvement in contextual instructional design may support the development of pedagogical reasoning and professional competence among pre-service teachers. In a similar vein, Forsler et al. (2024) emphasize that integrating content knowledge and pedagogical understanding in elementary education is essential to enabling teachers to design learning experiences that are developmentally appropriate and responsive to students' needs. These findings are particularly relevant to the challenges pre-service teachers face in designing ecosystem-based instructional modules for elementary learners.

Existing studies on teacher education and instructional module development generally fall into three major areas. First, several studies primarily evaluate the effectiveness or validity of learning modules as final products, focusing on student outcomes and instructional feasibility rather than examining how pedagogical competence develops during the design process itself (Purnomo et al., 2024). Second, research on project-based learning in teacher education often emphasizes collaborative learning outcomes or content mastery. In contrast, giving limited attention to how pre-service teachers negotiate pedagogical decisions, reflect on learners' needs, and construct instructional reasoning throughout authentic design experiences (Tsybulsky & Muchnik, 2021). Third, although studies such as Forsler et al. (2024) highlight the importance of integrating pedagogical and content knowledge in elementary education, limited research has examined how ecosystem-based module design in project-based learning settings

contributes to the development of pedagogical competence among pre-service elementary teachers.

The present study positions itself at the intersection of project-based learning, pedagogical competence development, and ecosystem-based *IPAS* module design. Rather than focusing solely on the quality of final instructional products, this study examines how pre-service teachers experience, interpret, and construct pedagogical understanding throughout the process of designing authentic modules. In doing so, the study offers a process-oriented pre-service that has remained underexplored in prior research on elementary teacher education. Its distinct contribution lies in conceptualizing pedagogical competence formation as a dynamic, reflective process embedded in authentic, project-based module design, rather than merely as an outcome represented in completed instructional products.

Accordingly, this study is guided by the following research questions:

- a) How do pre-service elementary teachers approach the design process of ecosystem-based *IPAS* learning modules?
- b) What are the characteristics and quality of the ecosystem-based *IPAS* modules developed by pre-service teachers for elementary students?
- c) What experiences, challenges, and perceptions do pre-service teachers report regarding the development of their pedagogical competence through this project?

The research findings are expected to contribute both theoretically and practically to teacher education, particularly in strengthening project-based pedagogical preparation for contextual and interdisciplinary learning in elementary schools.

2. Literature review

2.1 Development of pedagogical competence among pre-service elementary teachers

Pedagogical competence constitutes a central dimension of teacher professionalism, particularly in primary education, where teachers are required to translate disciplinary knowledge into developmentally appropriate learning experiences. In the context of pre-service elementary teachers, pedagogical competence extends beyond classroom management and lesson delivery to encompass understanding learner characteristics, designing meaningful instruction, selecting appropriate learning resources, and effectively evaluating student learning outcomes (Vitello et al., 2021). These competencies are especially critical in elementary education because instructional decisions must consider students' cognitive, linguistic, and socio-emotional development simultaneously.

Previous studies suggest that the development of pedagogical competence among pre-service teachers is strongly influenced by opportunities to connect theoretical coursework with authentic teaching practice. Research in teacher education consistently reveals that pre-service teachers often possess conceptual understanding of instructional principles but experience difficulties applying these principles in concrete lesson design and classroom implementation (Soro et al., 2022). This indicates that pedagogical competence is not formed solely through theoretical acquisition but through situated experiences that require pre-service teachers to make instructional decisions in authentic contexts. This connection is also strengthened in studies emphasizing learner needs, practice-oriented preparation, and project-based professional learning in teacher education (Bhatnagar & Many, 2022; Fazilla & Rangkuti, 2023; Martinez, 2022).

This perspective is closely related to the concept of Pedagogical Content Knowledge (PCK), introduced by Shulman (1986), which emphasizes the integration of subject matter knowledge and pedagogical understanding. In elementary science education, PCK involves not only mastering scientific concepts but also transforming them into representations, explanations, and meaningful learning activities for young learners. Thus, pedagogical competence and PCK should not be viewed as separate constructs; rather, pedagogical competence in elementary teaching is often operationalized through teachers' ability to enact PCK in instructional design and classroom practice.

From this perspective, examining how pre-service teachers design instructional modules is particularly crucial, as module design is a concrete space where pedagogical competence and PCK intersect. Through the design process, pre-service teachers must interpret curriculum goals, anticipate learners' needs, select contextual representations, and organize learning experiences into coherent instructional sequences. Therefore, instructional module design can function not only as a learning product but also as a reflective process through which pedagogical competence is constructed and demonstrated.

2.2 Design of integrated science teaching modules in primary education

The design of teaching modules in integrated science and social studies (*IPAS*) requires a coherent alignment between learning objectives, instructional activities, learning resources, and assessment strategies. In primary education, such modules must be contextually relevant and developmentally appropriate to support meaningful learning experiences. Constructive alignment theory highlights the importance of ensuring coherence among intended learning outcomes, learning activities, and assessment tasks (Abejuela et al., 2022). Therefore, module design is not merely a technical activity but a pedagogical process that reflects how teachers organize learning in ways that are responsive to learners' needs.

In ecosystem-based *IPAS* learning, pre-service teachers are challenged to transform interdisciplinary concepts—such as ecological relationships, sustainability, and human-environment interactions—into accessible and meaningful learning experiences for elementary students. This transformation process requires integrating scientific understanding, contextual awareness, and pedagogical reasoning, particularly when instructional content must be adapted to students' developmental characteristics and everyday experiences (Forsler et al., 2024; Glettler & Torkar, 2021; Shulman, 1986). Previous studies indicate that contextualized science modules grounded in local environments can enhance conceptual understanding, student engagement, and environmental literacy by connecting scientific ideas with authentic learning contexts (Tsybulsky & Muchnik, 2021). However, the literature also suggests that pre-service teachers frequently encounter difficulties in simplifying complex scientific content and integrating it with pedagogically meaningful approaches appropriate for young learners (Soro et al., 2022). Digital and interactive module studies further indicate that multimodal resources can support ecosystem learning when they are pedagogically aligned with learners' developmental characteristics (Çeken & Taşkın, 2022; Hikmaturosyidah & Racmadiarti, 2022; Kawuryan et al., 2025; Mansoor & Din, 2023; Surul & Septiliana, 2023).

These challenges demonstrate that module design in elementary science education involves more than content organization; it requires teachers to negotiate among curriculum demands, learners' developmental characteristics, and contextual learning experiences. Consequently, the quality of instructional modules reflects not only content mastery but also the extent to which pre-service teachers can operationalize pedagogical competence and PCK in learner-centered instructional practice (Vitello et al., 2021). In this sense, ecosystem-based module design

provides a meaningful context for examining how pedagogical competence is enacted through authentic instructional decision-making.

2.3 Project-based learning in teacher education

Project-Based Learning (PjBL) has been widely recognized as an effective pedagogical approach in teacher education, particularly for developing higher-order thinking, problem-solving skills, collaboration, and reflective practice. Unlike traditional instructional approaches, PjBL engages learners in authentic tasks that require sustained inquiry, product development, and contextual problem solving (Boss & Krauss, 2022; Eswaran, 2024; Javed, 2023; Saroyan, 2022). In teacher education, PjBL is especially valuable because it situates learning in tasks that closely resemble professional teaching practice.

Designing instructional modules through project-based activities requires pre-service teachers to identify authentic classroom needs, interpret curricular expectations, investigate pedagogical problems, and construct instructional solutions. Such processes encourage pre-service teachers not only to apply theoretical concepts but also to reflect on pedagogical decisions and learners' needs throughout the design experience (Boss & Krauss, 2022). In this regard, PjBL provides a pedagogical space where pedagogical competence and PCK can be actively constructed through authentic professional practice.

Previous studies have shown that project-based experiences enhance pre-service teachers' instructional confidence, creativity, and pedagogical decision-making (Guo, 2021; Liu et al., 2019; Rubino, 2024). Nevertheless, numerous studies still focus primarily on collaborative outcomes, content mastery, or product effectiveness, while giving less attention to how pre-service teachers develop pedagogical understanding during the design process itself. This limitation is particularly relevant in ecosystem-based *IPAS* learning, where pre-service teachers must simultaneously integrate interdisciplinary content knowledge, contextual environmental issues, and learner-centered pedagogical approaches.

Accordingly, this study positions project-based ecosystem module design not merely as an instructional assignment but as a professional learning process through which pre-service elementary teachers negotiate pedagogical meaning, construct instructional reasoning, and develop pedagogical competence in practice. By examining participants' experiences alongside the instructional products they created, this study contributes to a more integrated understanding of how PjBL facilitates the formation of pedagogical competence in elementary teacher education.

3. Method

3.1 Research design

This study employs a qualitative case study design to examine the development of pre-service elementary teachers' pedagogical competence through a project that involves designing ecosystem-based *IPAS* (Integrated Natural and Social Sciences) learning modules for elementary school students. A qualitative case study approach was considered appropriate, as the study aimed to obtain an in-depth understanding of a bounded educational case: the implementation of a project-based module design task within a specific teacher education course at a public university in Indonesia (Büchler et al., 2021).

The institutional setting, the participant group, the project focus, and the time frame bounded the case. Specifically, the study was conducted within one semester of the Elementary *IPAS* learning course in a primary teacher education program. The instructional project focused

on designing and developing ecosystem-based teaching modules for elementary students. This bounded case enabled an in-depth exploration of how pedagogical competence was developed through authentic project-based learning experiences within a clearly defined context.

The supervising lecturer provides the general project framework, including learning outcomes, project guidelines, and assessment criteria, while participants are given autonomy to select ecosystem subtopics, explore local environmental contexts, and develop contextually relevant instructional strategies. The final project output consists of a complete teaching module, evaluated for pedagogical coherence, contextual relevance, instructional design, and content appropriateness.

3.2 Research context and participants

The study was conducted in a primary teacher education program at a public university in Indonesia, specifically within the Elementary *IPAS* course, which focuses on integrated science and social studies learning at the elementary level. Participants comprised 30 pre-service elementary teachers enrolled in the course during the semester in which the study was conducted. Participants were organized into 10 small collaborative groups, with each group consisting of three students.

Purposive sampling was used at two levels. First, all 30 students were included in the observation and document analysis phases, as they were directly involved in the module development project. Second, for the interview phase, 12 participants were purposively selected based on the following criteria: active participation throughout the project process, representation of different levels of project performance (high, medium, and developing quality modules), willingness to participate in follow-up interviews, and ability to provide reflective accounts of their learning experiences. This sampling strategy was intended to ensure variation in perspective on the development of pedagogical competence.

3.3 Project implementation procedures

The project was implemented across one academic semester and consisted of several stages. In the initial stage, participants received an orientation to ecosystem-based *IPAS* learning, the principles of contextual learning, and project-based instructional design. Participants were subsequently grouped collaboratively and asked to identify ecosystem-related issues relevant to elementary students' local environments.

In the second stage, each group designed an instructional module consisting of learning objectives, learning activities, teaching materials, worksheets, assessment components, and contextual learning resources. During the drafting process, participants engaged in classroom discussions, consultations with lecturers, and peer feedback sessions to revise and refine their modules.

The final stage involved module presentation and revision. Each group presented their module to peers and lecturers, received feedback, and submitted the revised version as the final project output. Throughout the project, participants were encouraged to reflect on pedagogical decisions, learner needs, contextual relevance, and instructional feasibility.

3.4 Data collection procedures

Data were collected over one academic semester using three primary techniques: classroom and project observations, document analysis, and semi-structured interviews. Observations were conducted throughout the project's implementation across six scheduled sessions, covering the stages of project orientation, collaborative planning, module drafting,

revision, and final presentation. Each observation session lasted approximately 90 to 120 minutes. Field notes were systematically recorded using an observation protocol developed around key dimensions of pedagogical competence, including instructional planning, contextualization of ecosystem concepts, collaborative problem-solving, and alignment between learning objectives and learning activities.

Document analysis focused on the instructional modules produced by participants. The modules were analyzed to examine how pre-service teachers integrated ecosystem content, pedagogical strategies, contextual learning experiences, and assessment design within their instructional planning.

Semi-structured interviews were conducted with 12 selected participants after the project's completion. Each interview lasted approximately 30–45 minutes and explored participants' experiences, challenges, pedagogical considerations, and reflections during the module design process. All interviews were audio-recorded with participant consent and transcribed verbatim for analysis.

3.5 Module validation procedures

To strengthen the credibility and quality assessment of the instructional products, the developed modules were evaluated by two experts in elementary science education and instructional design. The expert validation process focused on four dimensions: (1) content accuracy and relevance, (2) pedagogical appropriateness for elementary students, (3) contextual integration of ecosystem themes, and (4) coherence between learning objectives, instructional activities, and assessment components.

The experts used a validation rubric adapted from previous instructional design studies. Each criterion was rated on a 4-point scale from 1 (needs major revision) to 4 (highly appropriate). Validation results were used descriptively to identify the strengths and weaknesses of the modules and to support the interpretation of participants' development of pedagogical competence.

Importantly, the validation results were not treated as quantitative findings but rather as complementary evidence integrated with observations, interviews, and document analysis. The expert feedback helped contextualize how participants' pedagogical competence was reflected in the instructional products they designed.

3.6 Data analysis techniques

The data were analyzed using thematic analysis. First, all interview transcripts, field notes, expert feedback, and module documents were read repeatedly to achieve data familiarization. This was followed by open coding, in which meaningful segments of data were identified and labeled inductively.

Initial codes included themes such as contextual adaptation, learner-centered design, difficulty simplifying scientific concepts, collaborative problem-solving, pedagogical reflection, and instructional alignment. These codes were subsequently grouped into broader categories representing dimensions of pedagogical competence development.

Through an iterative process, overarching themes were generated by identifying recurring patterns across the different data sources. The module validation results and expert comments were incorporated into the analysis as supporting evidence to underscore the interpretation of pedagogical competence reflected in participants' instructional products.

To strengthen the credibility of the findings, themes emerging from interviews were compared with evidence from observations, module documents, and expert validation results to ensure cross-source consistency.

3.7 Trustworthiness and ethical considerations

Several strategies were employed to enhance the study's trustworthiness. Data triangulation was conducted across observations, interviews, instructional documents, and expert validation results. Member checking was implemented by sharing interview summaries and preliminary interpretations with selected participants for confirmation and clarification. Peer debriefing was also conducted with colleagues in primary science education to review coding decisions and thematic interpretations. Furthermore, reflective memos were maintained throughout the research process to examine potential researcher assumptions and interpretive bias critically.

Ethical considerations were carefully observed throughout the study. Prior to participation, all participants received information regarding the purpose of the study, research procedures, voluntary participation, confidentiality, and their right to withdraw at any time without consequence. Written informed consent was obtained from all participants before data collection commenced. Participant identities were anonymized using pseudonyms to maintain confidentiality. The study adhered to ethical principles for educational research involving human participants.

4. Results

The findings are organized according to the three research questions, integrating evidence from classroom observations, document analysis of the ecosystem-based *IPAS* modules, and semi-structured interviews. This structure allows for a clearer presentation of how pre-service elementary teachers approached the module design process, the characteristics of the products they developed, and their perceptions of the development of pedagogical competence throughout the project.

4.1 Pre-service teachers' approaches to the module design process

The first research question examined how pre-service elementary teachers approached the design process of ecosystem-based *IPAS* learning modules. Observation data revealed that participants actively engaged in collaborative instructional planning and problem-solving throughout the project.

During the planning phase, most groups began by identifying ecosystem-related subtopics that were considered familiar to elementary students, such as food chains, plant-animal relationships, and environmental cleanliness. Their discussions frequently centered on how to make these concepts understandable for young learners. For example, field notes from the third observation session indicated that one group deliberately replaced technical terms, such as 'trophic level,' with simpler expressions, such as 'levels of living things in the food chain.'

This adaptation was also reflected in interview data. One participant explained: *"At first, we used scientific terms from the textbook, but later we realized that elementary students might not understand them. So, we changed the language and added examples from daily life, such as rice fields and fish ponds."* This finding suggests an emerging awareness of learner characteristics and age-appropriate instructional design.

Collaborative work was consistently observed across groups. Participants divided tasks related to content writing, visual design, activity development, and digital formatting. Peer

discussion was frequently used to resolve challenges, particularly when simplifying scientific concepts. For example, one participant stated: *"Sometimes we disagreed about how much content should be included, but discussion helped us focus on what was most crucial for children to understand."* These findings indicate that the project not only supported collaboration but also functioned as a space for negotiating pedagogical decisions, particularly in balancing content accuracy with learner accessibility.

4.2 Characteristics and quality of the developed ecosystem-based IPAS modules

The second research question focused on the characteristics and quality of the instructional modules produced by the participants. Document analysis indicates that the modules generally demonstrated satisfactory quality across four dimensions: content quality, instructional quality, technical quality, and suitability for elementary students.

Table 1. Expert validation scores for ecosystem-based IPAS modules

Criteria	Specific Items/Indicators	Average Scores (Scale 1–4)	Categories
Content Quality	Accurate content	3.3	Satisfactory
	Up-to-date content	3.3	Satisfactory
	Logically organized content	3.0	Fair
	Unbiased content	3.6	Very Satisfactory
	Coverage of ecosystem concepts (e.g., food chains, trophic levels)	3.7	Very Satisfactory
Instructional Quality	Clearly stated and measurable learning objectives	3.7	Very Satisfactory
	Appropriate level of difficulty for target users	3.5	Very Satisfactory
	Engaging and relevant activities	3.4	Very Satisfactory
	Alignment with pedagogical principles	3.2	Satisfactory
	Integration of contextual learning	3.3	Satisfactory
Technical Quality	Usability and navigation instructions	3.2	Satisfactory
	Clarity of graphics/images/audio	3.1	Satisfactory
	Visual synchronization	3.0	Fair
Overall Suitability	General suitability for elementary students	3.3	Satisfactory
	Potential to enhance student learning motivation	3.4	Very Satisfactory

To interpret the expert validation results, the average scores were categorized into 3.26–4.00 = Very Satisfactory, 2.51–3.25 = Satisfactory, 1.76–2.50 = Fair, and 1.00–1.75 = Needs Improvement. These categories were adapted to provide qualitative interpretations of the quantitative validation scores and were used to support cross-data analysis alongside observations and interview findings. The validation results were not treated as standalone measurements but were interpreted alongside participants' design decisions, collaborative interactions, and reflective explanations obtained during observations and interviews.

As shown in Table 1, the strongest aspect of the modules is the alignment between ecosystem content and learning objectives. High scores in ecosystem concept coverage (3.7) and clarity of learning objectives (3.7) indicate that most groups can identify essential scientific

ideas and translate them into instructional goals appropriate for elementary students. This finding is consistent with observation data, which reveal that participants frequently discuss how scientific terminology should be simplified without reducing conceptual meaning.

However, a closer analysis of the modules reveals essential variations in how pedagogical competence is enacted across groups. Groups with higher-quality modules tend to demonstrate stronger coherence between contextual examples, learning activities, and assessment tasks. For example, one high-performing group designs a module centered on the school garden ecosystem, in which students observe real plants and insects in the school environment before constructing simple food chain diagrams. The activities, guiding questions, and formative assessments are consistently tied to the same context. Interview data from this group suggest that participants intentionally design activities based on children's direct experiences because they believe elementary students learn more effectively through familiar and observable situations.

In contrast, several modules at the developing level exhibit partial inconsistency between learning objectives and instructional flow. In several cases, ecosystem concepts are presented accurately, but the activities remain largely text-based and teacher-directed, limiting opportunities for inquiry and contextual engagement. Observation data reveal that these groups often focused more heavily on completing content requirements than on anticipating learners' understanding processes. One participant admitted during the interview: "We were more concerned about finishing the module content first, and only later realized that several activities might still be too difficult for children."

The relatively lower scores in logical organization of content (3.0) and visual synchronization (3.0) further reflect these pedagogical tensions. Although participants generally understand the importance of contextual and learner-centered instruction, not all groups are equally successful in operationalizing these principles into coherent instructional sequences and technically integrated module designs. This suggests that the development of pedagogical competence among pre-service teachers is uneven and dynamic rather than uniform.

Importantly, triangulation across validation results, observations, and interviews indicates that module quality was closely associated with participants' ability to engage in pedagogical reflection during the design process. Groups that actively negotiate learners' needs, contextual relevance, and instructional clarity during collaborative discussions tend to produce more coherent modules. Thus, the findings suggest that the design process itself functioned as a critical site for the construction of pedagogical competence.

4.3 Pre-service teachers' perceptions of pedagogical competence development

The third research question explores participants' experiences, challenges, and perceptions of their development of pedagogical competence through the project. Interview findings generate four major themes.

Growth in Pedagogical Competence

Most participants reported increased confidence in lesson planning and greater awareness of student characteristics. One participant noted: *"Before this project, I only thought about the content. Now I think more about whether children can understand the examples and activities."* This statement suggests a shift from content-centered thinking toward learner-centered pedagogical reasoning.

This shift is also observable in the instructional products themselves. Modules developed later in the project demonstrated greater use of contextual questioning, simplified explanations,

and learner-oriented activities than the earlier drafts observed in classroom sessions. The convergence of interview reflections and document revisions indicates that pedagogical competence was developed not solely through theoretical understanding but through iterative cycles of design, feedback, and reflection.

Challenges in Development

A major challenge involved simplifying scientific concepts without losing conceptual accuracy. For example, one participant stated: *"The hardest part was explaining ecosystem relationships in simple words without making the meaning wrong."* In addition, several participants reported difficulties using digital tools for module production, particularly in layout design and visual integration.

Interestingly, the challenges reported by participants often reflected tensions between scientific accuracy and pedagogical accessibility. Observation data indicate that groups frequently revised explanations and examples after peer discussions, revealing that several concepts remained too abstract for elementary students. This indicates that the process of simplifying scientific content required more than content reduction; it involved pedagogical reasoning about how children interpret and construct meaning from contextual experiences.

Learning Through Projects

Participants consistently emphasized that the project helped bridge the gap between theoretical knowledge and classroom practice. As one participant explained: *"In theory classes, we learn about pedagogy, but through this project, we actually had to apply it for real elementary students."* This finding supports the value of project-based learning as an authentic context for competence development.

The findings further underscore that project-based learning functioned not only as an instructional strategy but also as a professional learning environment in which pre-service teachers constructed pedagogical understanding through authentic practice. The integration of collaborative negotiation, contextual problem solving, and reflective revision enabled participants to connect theoretical pedagogical concepts with concrete instructional decision-making.

Suggestions for Improvement

Several participants recommend more technical workshops on digital module design and longer project timelines. For example: *"More time and technical guidance would help us improve the visual quality of the modules."*

5. Discussion

The present study's research findings provide essential insights into how project-based module design can support the development of pedagogical competence among pre-service elementary teachers in the context of ecosystem-based *IPAS* instruction. By integrating evidence from observations, document analysis, and interviews, the discussion addresses not only what competencies emerged but also why these patterns may have occurred within the project context.

5.1 Development of pedagogical competence through authentic project engagement

The findings demonstrate that ecosystem-based module design functioned not merely as an academic assignment but as an authentic pedagogical experience through which pre-service teachers constructed instructional understanding in practice. Rather than developing pedagogical competence solely through theoretical exposure, participants developed competence through sustained engagement with real instructional problems, including adapting scientific concepts, anticipating learners' difficulties, and contextualizing content within elementary students' daily experiences.

This finding reinforces sociocultural perspectives on teacher learning, which emphasize that professional competence develops through participation in authentic pedagogical activities rather than through isolated theoretical instruction. The project-based design task created opportunities for participants to negotiate meaning collaboratively, justify instructional decisions, and reflect on learner accessibility. In this sense, pedagogical competence emerged as a situated and reflective process rather than a static acquisition of knowledge.

The findings also extend the concept of Pedagogical Content Knowledge (PCK) proposed by Shulman (1986) by demonstrating how pre-service teachers gradually transformed disciplinary ecosystem knowledge into forms accessible to elementary students. The transition from technical-scientific terminology to contextual, age-appropriate explanations reflects the development of pedagogical reasoning that integrates content understanding with learner awareness. This interpretation is further supported by recent syntheses and curriculum-design studies that emphasize the importance of strengthening teachers' content knowledge for teaching and their understanding of the nature of science (Hanuscin et al., 2025; Jain et al., 2024).

This interpretation is consistent with Li (2025), which emphasizes that authentic instructional experiences significantly support the development of pedagogical awareness and reflective teaching practices. Research by Tangkin (2022), for example, highlights that microteaching and practice-oriented learning activities encourage pre-service teachers to reconsider how instructional delivery aligns with the characteristics of elementary students. Similarly, Alghifari et al. (2023) note that pedagogical competence develops more meaningfully when teacher candidates actively engage in learner-centered instructional processes rather than merely studying pedagogical theories conceptually.

Importantly, the findings underscore that project-based learning contributes to competence development not because projects automatically improve teaching skills, but because they expose pre-service teachers to authentic pedagogical dilemmas that require instructional adaptation and reflective decision-making. Thus, the pedagogical value of the project lies in its ability to create a professional learning environment where theoretical knowledge is continuously tested, negotiated, and reconstructed through practice.

From a practical perspective, this finding implies that elementary teacher education programs should integrate more authentic design-based learning experiences into pedagogy courses. Tasks involving contextual module development, collaborative lesson design, and reflective revision may provide stronger opportunities for pre-service teachers to internalize pedagogical reasoning than lecture-based instruction alone.

5.2 Quality of the developed ecosystem-based IPAS modules

The findings reveal that the pre-service teachers generally demonstrated adequate competence in aligning ecosystem content with instructional objectives and contextual elementary learning experiences. However, the variation in module quality indicates that the

development of pedagogical competence among pre-service teachers remains uneven and multidimensional.

The strongest aspect of the modules was the contextualization of ecosystem concepts in familiar environmental settings, such as school gardens, rice fields, and household waste management. This suggests that participants were increasingly able to connect interdisciplinary scientific ideas to students' lived experiences, an essential principle in elementary *IPAS* instruction. The findings support previous research indicating that contextual learning environments strengthen meaningful understanding and learner engagement in elementary science education.

At the same time, lower performance in instructional sequencing, visual integration, and module organization suggests that pre-service teachers may still struggle to translate pedagogical intentions into coherent instructional architecture. This finding is theoretically crucial because it demonstrates that pedagogical competence is not limited to understanding instructional principles conceptually; it also involves operationalizing those principles into usable, learner-friendly instructional products.

This interpretation aligns with the findings of Fitrianto and Farisi (2025), who report that teachers and pre-service teachers often experience challenges in integrating instructional media and translating pedagogical ideas into effective classroom practice.

This finding contributes theoretically by extending current understandings of pedagogical competence in elementary teacher education. The study underscores that competence development should be conceptualized as an integrative process that simultaneously involves content adaptation, contextual reasoning, instructional sequencing, and visual communication. Thus, effective teacher preparation requires not only strengthening subject-matter knowledge but also scaffolding pre-service teachers' capacity to design coherent, learner-centered instructional experiences.

In practice, these findings imply that teacher education institutions should provide more structured support for instructional media design, curriculum alignment, and multimodal learning representations. Workshops on visual literacy, module architecture, and digital instructional design may help pre-service teachers bridge the gap between pedagogical ideas and instructional implementation.

5.3 Prospective teachers' perceptions of competence development

Participants' reflections reveal that the project meaningfully contributed to their perception of becoming more pedagogically aware and more professionally prepared for elementary instruction. Numerous participants described a shift from focusing primarily on content delivery toward considering how elementary students understand, experience, and engage with learning activities. This shift reflects an emerging learner-centered orientation, which constitutes an essential dimension of pedagogical competence in primary education.

Importantly, the findings indicate that pedagogical growth occurred through iterative cycles of reflection, revision, and collaborative negotiation rather than through linear mastery. Participants frequently revised explanations, examples, and instructional activities after discussing potential misunderstandings among learners with peers. This suggests that pedagogical competence is developed dynamically through reflective practice embedded within authentic instructional tasks.

The persistent difficulty participants experienced in simplifying ecosystem concepts while maintaining scientific accuracy is also theoretically significant. This challenge highlights the inherent tension within PCK development between preserving disciplinary rigor and ensuring

pedagogical accessibility. The findings therefore reinforce the idea that transforming scientific knowledge into elementary-level instruction is not a straightforward reduction process, but a complex act of pedagogical interpretation.

Another essential implication concerns technological pedagogical competence. Difficulties related to layout design, visual integration, and digital presentation indicate that pedagogical competence in contemporary elementary education increasingly requires integrating technological and visual communication skills. Therefore, pedagogical preparation for pre-service teachers should not only emphasize instructional theory but also include opportunities to develop digital instructional design competence relevant to contemporary classroom contexts. This need is also consistent with broader higher-education discussions on digital learning resources and life-cycle-oriented instructional materials (Akintayo et al., 2024; Viere et al., 2024).

Overall, the findings suggest that project-based ecosystem module design provides a meaningful pedagogical environment for supporting pre-service teachers' professional learning. The study contributes to the teacher education literature by demonstrating that pedagogical competence develops most meaningfully when pre-service teachers are positioned as active instructional designers who must simultaneously negotiate authentic pedagogical, contextual, and interdisciplinary challenges.

6. Conclusion and implications

This study demonstrates that project-based ecosystem module design can function as an authentic pedagogical learning space through which pre-service elementary teachers construct pedagogical competence in practice. The findings indicate that pedagogical competence development occurs not merely through the production of instructional modules, but through iterative processes of contextual adaptation, pedagogical negotiation, reflection, and collaborative decision-making during authentic design experiences.

The study contributes theoretically by extending current understandings of pedagogical competence and Pedagogical Content Knowledge (PCK) in elementary teacher education. Rather than conceptualizing competence as a static outcome reflected only in final instructional products, the findings suggest that pedagogical competence develops dynamically through interactions among content understanding, learner-centered reasoning, contextual awareness, and instructional design practice. This process-oriented perspective provides a more integrated understanding of how pre-service teachers construct pedagogical meaning within project-based learning environments.

In practice, the findings underscore the need for teacher education programs to provide more authentic and reflective instructional design experiences that enable pre-service teachers to connect pedagogical theory with contextual classroom practice. Ecosystem-based *IPAS* projects, collaborative module development, and reflective revision activities may serve as meaningful pedagogical strategies for strengthening learner-centered instructional competence in elementary education. In addition, greater institutional support in instructional media design, digital literacy, and curriculum alignment is necessary to help pre-service teachers translate pedagogical ideas into coherent instructional products.

Despite these contributions, this study is limited by its qualitative case-study design, conducted within a single institutional context and involving a relatively small group of participants. Therefore, the findings should be interpreted in context rather than generalized across teacher education settings. Future research is recommended to examine how

pedagogical competence developed through project-based instructional design is sustained and transferred into authentic classroom teaching practices across different educational contexts and over longer periods of professional preparation.

7. Limitation

This study is limited by its qualitative case study design conducted within a single teacher education program involving a relatively small group of pre-service elementary teachers, which limits the broader generalizability of the findings. In addition, the study was conducted over a single academic semester and therefore did not examine the long-term development or transfer of pedagogical competence into classroom practice. Future research is recommended to involve multiple institutions, larger participant groups, and longitudinal approaches to provide a more comprehensive understanding of the development of pedagogical competence in teacher education.

Credit authorship contribution statement

First Author: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing – original draft preparation. **Second Author:** Supervision, Validation, Writing – review and editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement

The data that support the research findings are available from the corresponding author upon reasonable request. As the data include information from human participants, they are not publicly available in order to protect participant privacy and confidentiality.

Ethical Declaration

This study was conducted in accordance with the Declaration of Helsinki, and informed consent was obtained from all participants. Prior to enrolment, participants were fully informed about the study's purpose, procedures, and their right to withdraw at any time without consequence.

Declaration of AI statement

"Portions of this manuscript were drafted/edited/enhanced using ChatGPT-4 (OpenAI). The authors used this tool specifically to improve grammar and clarity and to draft an initial version of the Introduction section. All AI-generated content was thoroughly reviewed, edited, and validated by the authors, who take full responsibility for the final content. The authors provided the prompts and edited the output to ensure accuracy and relevance."

References

- Abejuela, H. J. M., Castillon, H. T., & Sigod, M. J. G. (2022). Constructive alignment of higher education curricula: The case of a Philippine state university. *Asia Pacific Journal of Social and Behavioral Sciences*, 20, 48–72. <https://doi.org/10.57200/apjsbs.v20i0.288>
- Alghifari, G. A., Ibrahim, F., & Parhan, M. (2023). Implementation of pedagogic competence through the humanist learning perspective of Ki Hadjar Dewantara. *Primary: Jurnal Pendidikan Guru Sekolah Dasar*, 12(3), 680–688.

<https://doi.org/10.33578/jpfkip.v12i3.9685>

- Akintayo, O. T., Eden, C. A., Ayeni, O. O., & Onyebuchi, N. C. (2024). Evaluating the impact of educational technology on learning outcomes in the higher education sector: A systematic review. *International Journal of Management & Entrepreneurship Research*, 6(5), 1395–1422. <https://doi.org/10.51594/ijmer.v6i5.1091>
- Bhatnagar, R., & Many, J. (2022). Teachers using social emotional learning: Meeting student needs during COVID-19. *International Journal of Technology in Education*, 5(3), 518–534. <https://doi.org/10.46328/ijte.310>
- Boss, S., & Krauss, J. (2022). *Reinventing project-based learning: Your field guide to real-world projects in the digital age*. International Society for Technology in Education.
- Büchler, J.-P., Brüggelambert, G., de Haan-Cao, H. H., Sherlock, R., & Savanevičienė, A. (2021). Towards an integrated case method in management education—developing an ecosystem-based research and learning journey for flipped classrooms. *Administrative Sciences*, 11(4), 113. <https://doi.org/10.3390/admsci11040113>
- Çeken, B., & Taşkın, N. (2022). Multimedia learning principles in different learning environments: A systematic review. *Smart Learning Environments*, 9(1), 19. <https://doi.org/10.1186/s40561-022-00200-2>
- Eswaran, U. (2024). Project-based learning: Fostering collaboration, creativity, and critical thinking. In *Enhancing education with intelligent systems and data-driven instruction* (pp. 23–43). IGI Global. <https://doi.org/10.4018/979-8-3693-2169-0.ch002>
- Fazilla, S., & Rangkuti, Y. M. (2023). Professional ability of prospective elementary school teachers through a project-based learning model in primary education. *SITTAH: Journal of Primary Education*, 4(1), 44–60. <https://doi.org/10.30762/sittah.v4i1.917>
- Fitrianto, I., & Farisi, M. (2025). Integrating local wisdom into 21st-century skills: A contextual framework for culturally relevant pedagogy in rural classrooms. *International Journal of Post Axial: Futuristic Teaching and Learning*, 3(2), 109–121. <https://doi.org/10.59944/postaxial.v3i2.444>
- Forsler, A., Nilsson, P., & Walan, S. (2024). Collective pedagogical content knowledge for teaching sustainable development. *International Journal of Science and Mathematics Education*, 22(6), 1197–1214. <https://doi.org/10.1007/s10763-023-10421-7>
- Geletu, G. M. (2022). The effects of teachers' professional and pedagogical competencies on implementing cooperative learning and enhancing students' learning engagement and outcomes in science: Practices and changes. *Cogent Education*, 9(1), 2153434. <https://doi.org/10.1080/2331186X.2022.2153434>
- Glettler, C., & Torkar, G. (2021). First-year pre-service primary school teachers' conceptual structure of ecosystem ecology concepts. *Action Research and Innovation in Science Education*, 4(1), 25–31. <https://doi.org/10.51724/arise.41>
- Guo, P. (2021). Project-based learning: Connotation, characteristics, and misunderstandings. *Region-Educational Research and Reviews*, 3(2), 22. <https://doi.org/10.32629/rerr.v3i2.319>
- Hanuscin, D., Borda, E., Melton, J., & Mikeska, J. N. (2025). Designing educative curriculum materials for teacher educators: Supporting pre-service elementary teachers' content knowledge for teaching about matter and its interactions. *International Journal of Science and Mathematics Education*, 23(1), 193–213. <https://doi.org/10.1007/s10763-024-10453-7>
- Hikmaturosyidah, N., & Racmadiarti, F. (2022). The development of an interactive e-book based on a multiple-intelligences ecosystem topic to train creative thinking skills. *Journal of*

- Biology Education*, 11(1), 89–101. <https://doi.org/10.15294/jbe.v11i1.55256>
- Jain, J., Lee, Y. L., & Mok, S. J. (2024). A systematic review of pedagogical content knowledge for teaching the nature of science. *Asian Journal of University Education*, 20(1), 138–151. <https://doi.org/10.24191/ajue.v20i1.25738>
- Javed, F. (2023). Transformative learning strategies for successful teaching and learning in transforming higher education. In *Active and transformative learning in STEAM disciplines* (pp. 125–152). Emerald Publishing Limited. <https://doi.org/10.1108/978-1-83753-618-420231007>
- Kawuryan, S. P., Wuryandani, W., Supartinah, S., Malagola, Y., & Umardianti, U. (2025). Digital module of *Pancasila* education and *IPAS* in elementary school: Preliminary research. In *Proceedings of the 8th International Conference on Education Innovation (ICEI 2024)* (pp. 1021–1037). Atlantis Press. https://doi.org/10.2991/978-2-38476-360-3_89
- Kellogg, W., Dhaliwal, N., Barrette-Ng, I., Gelderloos, O., Hartig, J., Lisuk, J., & McLaughlin, C. (2024). Outreach, education, and knowledge mobilization for effective use of ecosystem-based approaches. *Aquatic Ecosystem Health & Management*, 27(2), 49–63. <https://doi.org/10.14321/ae hm.027.02.49>
- Li, H. (2025). Reflective practice for pre-service teachers' professional development. *SAGE Open*, 15(3), 21582440251363136. <https://doi.org/10.1177/21582440251363136>
- Liu, H.-H., Wang, Q., Su, Y.-S., & Zhou, L. (2019). Effects of project-based learning on teachers' information teaching, sustainability, and ability. *Sustainability*, 11(20), 5795. <https://doi.org/10.3390/su11205795>
- Mansoor, S., & Din, M. (2023). An analysis of the single national curriculum of general science at the primary level through the lens of 21st-century skills. *Pakistan Journal of Educational Research*, 6(2). <https://doi.org/10.52337/pjer.v6i2.831>
- Martinez, C. (2022). Developing 21st-century teaching skills: A case study of teaching and learning through project-based curriculum. *Cogent Education*, 9(1), 2024936. <https://doi.org/10.1080/2331186X.2021.2024936>
- Purnomo, Y. W., Nabillah, R., Aziz, T. A., & Widodo, S. A. (2024). Fostering mathematical connections and habits of mind: A problem-based learning module for elementary education. *Infinity Journal*, 13(2), 333–348. <https://doi.org/10.22460/infinity.v13i2.p333-348>
- Rubino, S. (2024). *Project-based learning and its impact on student engagement, well-being, and learning outcomes: A study of teachers' perspectives*. Arkansas State University.
- Saroyan, A. (2022). *Fostering creativity and critical thinking in university teaching and learning: Considerations for academics and their professional learning*. OECD. <https://doi.org/10.1787/09b1cb3b-en>
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4–14. <https://doi.org/10.3102/0013189X015002004>
- Soro, S. H., Handayani, S., Mulyana, N., Mulyana, R., & Hadian, T. (2022). Manajemen supervisi akademik dalam meningkatkan kompetensi pedagogik guru di SDN Dewi Sartika CBM Kota Sukabumi. *Primary: Jurnal Pendidikan Guru Sekolah Dasar*, 11(6), 1726–1739. <https://doi.org/10.33578/jpfkip.v11i6.9346>
- Surul, R., & Septiliana, L. (2023). Analysis of the implementation of *IPAS* (natural and social sciences) learning in the *Merdeka* Curriculum. *EDUCATIO: Journal of Education*, 8(3), 320–328. <https://doi.org/10.29138/educatio.v8i3.1301>
- Tangkin, W. P. (2022). Analisis microteaching tahap pembukaan pada mahasiswa PGSD dalam mata kuliah PSAP matematika SD. *Primary: Jurnal Pendidikan Guru Sekolah Dasar*,

- 11(4), 1185–1193. <https://doi.org/10.33578/jpkip.v11i4.9091>
- Tsybulsky, D., & Muchnik-Rozanov, Y. (2021). Project-based learning in science-teacher pedagogical practicum: The role of emotional experiences in building pre-service teachers' competencies. *Disciplinary and Interdisciplinary Science Education Research*, 3(1), 9. <https://doi.org/10.1186/s43031-021-00037-8>
- Viere, T., Lehmann, J., Miao, Z. C., Harding, K., Strothmann, P., Weyand, S., Wright, L., et al. (2024). Global state of the art of teaching life cycle assessment in higher education. *The International Journal of Life Cycle Assessment*, 29(7), 1290–1302. <https://doi.org/10.1007/s11367-024-02319-5>
- Vitello, S., Greateorex, J., & Shaw, S. (2021). *What is competence? A shared interpretation of competence to support teaching, learning, and assessment*. Cambridge University Press & Assessment. <https://doi.org/10.17863/CAM.110829>
- Wang, N., Pasawano, T., Sangsawang, T., & Pigultong, M. (2024). Data-driven analysis of the impact of teaching quality on graduate employment in higher vocational colleges in Hefei. *Journal of Applied Data Sciences*, 5(1), 242–255. <https://doi.org/10.47738/jads.v5i1.169>