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Technological, Pedagogical, and Content Knowledge (TPACK) of Pre-Service Teachers and their Preparedness in Teaching Science: Basis for Intervention Plan

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Abstract

To get science teachers ready for 21st-century classrooms, they need to know a lot about how technology, teaching methods, and subject matter knowledge (TPACK) all work together in the real world. This study looks into how ready future science teachers at Calabanga Community College in the Philippines are to teach well and meet current educational standards. The research sought to evaluate the TPACK competencies of prospective science educators and ascertain their readiness for inquiry-based, technology-enhanced instruction. Utilizing the tenets of Constructivism, Connectivism, and Thorndike's Law of Readiness, the study aimed to discern the strengths and weaknesses in instructional readiness. A descriptive quantitative design was utilized, involving 35 mentor evaluations—consisting of college instructors and cooperating teachers—who evaluated pre-service teachers in five domains: science content knowledge, pedagogical principles, technology integration, classroom management, and the interrelationship among TPACK elements. Mean scores and comparisons between mentor groups were used to look at the data. The findings indicated that pre-service teachers possessed a commendable level of TPACK (overall mean score = 3.87), yet they were only moderately prepared to implement inquiry-based teaching, formative assessment strategies, and adaptive technologies.There were no statistically significant differences between the evaluations of college instructors and cooperating teachers, which means that all mentor groups had the same ideas about the evaluations. The study concludes that foundational TPACK competencies exist; however, specific interventions are required to augment conceptual fluency and improve instructional responsiveness. In response, the STEP-UP (Science Teacher Empowerment Program – Uplifting Potential) is suggested as a structured professional development program that focuses on workshops, peer feedback, and hands-on learning. These results show how important it is to intentionally develop TPACK in order to create science teachers who are knowledgeable about science, good with technology, and adaptable in their teaching.

Keywords*:* *TPACK, Pre-service Teachers, Science Education, Instructional Readiness*

INTRODUCTION

Background and rationale

The needs of science education in the 21st century have changed what teachers are expected to do, especially when it comes to combining technology with teaching and learning. Effective teaching no longer depended only on knowing a lot about the subject; it also needed the ability to create learning experiences that were inquiry-driven, digitally enhanced, and adaptable to different types of learners. In the Philippines, the K–12 curriculum, ASEAN integration, and the global push for digital literacy have all made it even more important for science teachers to be knowledgeable, flexible in their teaching, and good with technology. Even with these changes, many new teachers still didn't have much experience using educational technologies in a meaningful way when they started teaching. Their teaching methods were often still centered on the teacher, and they didn't have the flexible techniques they needed to encourage scientific reasoning, student engagement, and understanding of concepts. This gap between what they learned in theory and how they used it in the classroom made people worry about whether they were ready to meet the changing needs of science education.

The Technological Pedagogical Content Knowledge (TPACK) framework offered a thorough perspective for assessing teacher proficiency. It focused on the overlap of three main areas: technology, pedagogy, and content, and how bringing them all together helped with good teaching. TPACK had become known around the world, but it was still not well understood how to use it in local teacher education programs, especially in provincial colleges. These institutions frequently encountered difficulties in resource accessibility, professional development, and exposure to novel instructional models.

Based on Constructivism, Connectivism, and Thorndike's Law of Readiness, this study looked at the TPACK skills of future science teachers at Calabanga Community College. The goal was to find out what was good and bad about the teaching, especially in areas like inquiry-based learning, formative assessment, and using technology in the classroom. The results led to the creation of STEP-UP (Science Teacher Empowerment Program – Uplifting Potential), a structured intervention meant to improve conceptual fluency, responsiveness to instruction, and reflective use of technology. In the end, the study added to the larger conversation about how to prepare teachers by calling for intentional, evidence-based methods that help teachers in the Philippines become more scientifically literate, digitally skilled, and adaptable in their teaching.

Review of related literature

Technology has become a key part of teaching in the 21st century, especially in science classes where new ways of teaching are often needed to help students understand abstract ideas. Mishra and Koehler (2006) came up with the Technological Pedagogical Content Knowledge (TPACK) framework, which is a strong way to understand how teachers combine their knowledge of content, teaching methods, and technology to make learning experiences that matter. This review integrates contemporary literature pertaining to the fundamental domains of TPACK—technological knowledge, pedagogical knowledge, and content knowledge—along with their intersections, emphasizing both international and Philippine studies pertinent to the preparation of pre-service science teachers.

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Technological Knowledge

Teachers must now be technologically fluent in order to create interactive, inquiry-based learning environments. Boz and Özerbaş (2020) stressed that the beliefs and self-evaluated skills of pre-service teachers greatly affect how willing they are to use technology. Memis et al. (2023) discovered that although pre-service science teachers acknowledged the significance of digital tools, their utilization was superficial, frequently restricted to presentation software rather than instruments that promote scientific inquiry. Laius and Pressman (2024) demonstrated that a limited number of pre-service teachers recognized the pedagogical potential of ICT, with numerous individuals unable to perceive its significance in inquiry-based learning.

Duan and Exter (2024) investigated idealized notions of technology integration, noting that while pre-service teachers displayed enthusiasm, their pedagogical beliefs showed considerable variability. Concerns about fairness, safety, and distraction persisted, suggesting that digital proficiency must be coupled with critical evaluation. Siregar et al. (2024) and Prachagool et al. (2022) demonstrated that, notwithstanding improvements in digital literacy among pre-service teachers, challenges such as limited access, diminished confidence, and inadequate institutional support continued to hinder substantial integration.

Pedagogical Knowledge

Pedagogical knowledge includes the ways that teachers help students learn, keep their classrooms in order, and change their lessons. Carlson and Daehler (2019) underscored the significance of pedagogical content knowledge (PCK) in customizing instruction to align with student cognition. Nevertheless, studies conducted by Juhji and Nuangchalerm (2020) and Adu (2020) indicated that numerous pre-service teachers faced challenges in applying pedagogical theory to practice, especially in inquiry-based science education. Lekhu (2023) found that beliefs about how well teachers could teach were closely linked to how well they were prepared, and that there were still problems with classroom management and assessment design in training programs.

Absolor (2023) emphasized that although pre-service teachers exhibited confidence in instructional strategies and classroom management, they demonstrated a deficiency in comprehensive curriculum understanding. Weyer et al. (2024) validated that initial exposure to pedagogical content in teacher education exerted an enduring influence, while underscoring the necessity for longitudinal tracking to evaluate developmental progress over time.

Content Knowledge

Knowledge of the subject matter is still the most important part of teaching science well. Salinas (2022) advocated for inquiry-based methods courses to enhance scientific comprehension, whereas Long et al. (2019) illustrated that microteaching and feedback enhanced content mastery and certification results. Talib et al. (2023) identified enduring misconceptions among pre-service teachers, especially regarding mathematical and scientific concepts such as rate of change and motion. These results corroborated Shulman's (1986) assertion that content knowledge must be profoundly intertwined with pedagogical expertise to facilitate student learning.

Integration of TPACK Elements

TPACK is known for combining technology, teaching, and content. Mishra and Koehler (2006) asserted that effective teaching arises not from isolated domains but from their convergence. Memis et al. (2023) and Teknowijoyo (2024) found that even though pre-service teachers were good at using digital platforms, they often didn't have the reflective practice they needed to make sure that the tools they used were in line with their learning goals. Cojorn and Sonsupap (2024) emphasized that genuine TPACK integration requires deliberate design and contextual awareness, rather than mere operational competence.

Espinosa et al. (2024) and Kesawan et al. (2024) pinpointed difficulties in classroom management, formative assessment, and inquiry facilitation—domains requiring dynamic application of TPACK. Investigations conducted by Tanak (2020), Sari and Wulandari (2022), and Carré et al. (2023) corroborated the application of inquiry-based and reflective methodologies to augment instructional adaptability and professional insight.

Implications for Philippine Education

In the Philippines, it is very important to prepare teachers with TPACK. The Philippine Professional Standards for Teachers (DepEd Order No. 42, s. 2017) and CHED Memorandum Order No. 104, s. 2017 stress the importance of being able to use ICT in the classroom and being a good teacher. However, research conducted by Ramos et al. (2020) and Santos & Castro (2021) indicated that numerous pre-service teachers still exhibited a deficiency in confidence and practical experience in implementing TPACK in actual classroom settings. Antonio (2024) advocated for structured interventions and adaptable training models to rectify these deficiencies, particularly in provincial colleges where resource accessibility may be constrained.

Statement of the problem

This study investigated how prepared pre-service science teachers in an in-depth understanding of science concepts, select appropriate teaching strategies and approaches, and using technologies and laboratory equipment that suit science lessons. The result of this study was used to design a teacher education training program to strengthen student teachers' TPACK development to optimize students' learning experiences and outcomes.

Specifically, it sought to answer the following questions:

1. What is the level of Technological, Pedagogical, and Content Knowledge of the science pre-service teachers along
   1.1 Depth of Science Knowledge
   1.2 Teaching and Learning Principles
   1.3 Technology Integration into Science Lessons
   1.4 Skills in Classroom Management, Assessment, and Differentiation
   1.5 Interplay Among Technology, Pedagogy, and Content
2. What is the extent of Technological, Pedagogical, and Content Knowledge preparedness of the science pre-service teachers as revealed by the assessment of the mentors along with
   2.1 Mastery of Science Concepts and Principles
   2.2 Breadth of Pedagogical Strategies

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2.3 Technology Integration to Science Teaching

2.4 Application of Skills in Classroom Management, Assessment, and Differentiation

2.5 Integration of TPACK into Science Teaching

3. What is the significant difference in the level of Technological, Pedagogical, and Content Knowledge of the science pre-service teachers between the two groups of mentors?
4. What is the significant difference in the extent of preparedness of the science pre-service teachers between the assessment of the two groups of mentors?
5. Based on the results, what intervention plan can be proposed?

Hypotheses

The following hypotheses guided this study:

1. There is no significant difference in the level of Technological, Pedagogical, and Content Knowledge of the science pre-service teachers between the two groups of mentors.
2. There is no significant difference in the extent of preparedness of the science pre-service teachers between the assessments of the two groups of mentors.

MATERIALS AND METHODS

This study utilized a descriptive quantitative research design to assess the Technological, Pedagogical, and Content Knowledge (TPACK) of pre-service science teachers and their readiness for classroom instruction. The design was selected to systematically collect mentor evaluations and produce empirical data that could guide the formulation of a targeted intervention program. The study included 35 mentors who were directly responsible for overseeing pre-service teachers during their internships. These mentors included 15 college instructors, such as Teaching Internship Coordinators from Calabanga Community College, and 20 cooperating teachers from different high schools in Calabanga, Camarines Sur. Their insights were deemed essential in evaluating the instructional competencies of the pre-service teachers.

The researcher created a 50-item Likert scale questionnaire to collect data. Experts in education and statistics checked it for accuracy. The instrument was divided into two main parts. The first part looked at TPACK in five areas: science content knowledge, pedagogical principles, technology integration, classroom management, and the connections between TPACK elements. The second part looked at how ready the teacher was to teach using a four-point scale from "Not Prepared" to "Fully Prepared."

The research process started by getting permission from the schools that were going to take part and getting approval from the institution. After the instrument was validated, the questionnaire was given out online using Google Forms. We gathered, encoded, and organized the answers so that we could do statistical analysis on them. The findings subsequently informed the design of the STEP-UP (Science Teacher Empowerment Program – Uplifting Potential) intervention plan. The analysis of the data used both descriptive and inferential statistics. We used frequency counts, percentages, and weighted means to find out how high TPACK and instructional readiness were

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overall. Independent samples t-tests were performed at a 0.05 level of significance using SPSS software to analyze variations in mentor evaluations.

RESULTS

Table 1 shows the level of Technological, Pedagogical, and Content Knowledge of the science pre-service teachers, along with depth of science knowledge, teaching and learning principles, technology integration into science lessons, skills in classroom management, assessment, and differentiation, and interplay among technology, pedagogy, and content. This table is perceived by the mentors of the pre-service teachers and it was interpreted as emerging, developing, proficient, and advanced.

Table 1.1. The Level of Technological, Pedagogical, and Content Knowledge of the Science Pre-service Teachers, along with the Depth of Science Knowledge

Indicators	WM	Rank	Interpretation
1.Demonstrates a comprehensive understanding of core scientific concepts, principles, and theories	2.83	3	Proficient
2. Identifies and effectively addresses common misconceptions in science.	2.80	4	Proficient
3. Possesses a broad and deep knowledge based on science relevant to their teaching area	2.91	1	Proficient
4. Applies scientific reasoning and critical thinking skills effectively.	2.86	2	Proficient
5. Displays proficiency in scientific inquiry processes and methods.	2.77	5	Proficient
General Weighted Mean	2.83		Proficient

Table 1.1 shows how much Technological, Pedagogical, and Content Knowledge (TPACK) science pre-service teachers have, focusing on the Depth of Science Knowledge dimension. The general weighted mean of 2.83 showed that pre-service teachers have a good understanding of scientific content knowledge that is necessary for effective teaching. The top-rated sign, "Possesses a broad and deep knowledge based on science relevant to their teaching area" (WM = 2.91), shows that these future teachers know a lot about the subjects they will be teaching. This finding aligns with Salinas (2022), who highlighted that inquiry-based science methods courses substantially improve pre-service teachers' content mastery and instructional confidence. The second-highest indicator, "Applies scientific reasoning and critical thinking skills effectively" (WM = 2.86), reinforced the idea that pre-service teachers can get students to think critically and analytically. Wangchuk et al. (2023) contend that scientific reasoning is an essential competency for promoting conceptual understanding and inquiry in science classrooms, underscoring the significance of this skill in teacher preparation. Nonetheless, the least-rated indicators—“Displays proficiency in

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scientific inquiry processes and methods" (WM = 2.77) and "Identifies and effectively addresses common misconceptions in science" (WM = 2.80)—underscore domains necessitating focused assistance. These results corroborate the findings of Suprapto (2020), who observed that misconceptions endure in the absence of diagnostic strategies and inquiry facilitation skills among educators. The literature indicates that although pre-service teachers possess sufficient theoretical knowledge, their capacity to convert this into inquiry-based, student-centered instruction is still lacking (Tanak, 2020; Carré et al., 2023). Sari and Wulandari (2022) pinpointed prevalent instructional challenges, including difficulties in facilitating student inquiries, maintaining engagement, and cultivating confidence skills intricately linked to inquiry proficiency. To fill these gaps, teacher education programs need to offer scaffolded, hands-on learning experiences that focus on formative assessment, strategies for changing concepts, and real scientific investigation. Cojorn and Sonsupap (2024) say that to improve TPACK in science education, teachers need to know the material well, be flexible in their teaching methods, and be comfortable using technology to help students learn more deeply and become more scientifically literate.

Table 1.2. The Level of Technological, Pedagogical, and Content Knowledge of the Science Pre-service Teachers along with Teaching and Learning Principles

Indicators	WM	Rank	Interpretation
1. Applies a range of effective instructional strategies appropriate for diverse learners.	3.00	1	Proficient
2. Develops engaging and well-structured lesson plans that promote student learning.	2.97	2.5	Proficient
3. Demonstrates understanding and application of various learning theories.	2.97	2.5	Proficient
4. Adapts content representation to meet the needs and learning styles of diverse learners.	2.91	4	Proficient
5. Anticipates and addresses common student understandings and misconceptions.	2.86	5	Proficient
General Weighted Mean	2.94		Proficient

Table 1.2 showed how much science pre-service teachers knew about technology, teaching, and content (TPACK) in relation to the principles of teaching and learning. The overall weighted mean of 2.94, which is considered "Proficient," showed that the pre-service teachers had a good understanding of the basic teaching methods needed for effective science instruction. The top-rated indicator, "Applied a range of effective instructional strategies appropriate for diverse learners" (WM = 3.00), showed that they could change their teaching style to fit the needs of different students. This finding corroborated Blaz (2023), who asserted that differentiated instruction improved engagement and equity in heterogeneous classrooms. The indicators "Developed engaging and well-structured lesson plans" and "Demonstrated understanding and application of various learning theories" (WM = 2.97) showed that the pre-service teachers could make coherent, learner-centered lessons based on solid theoretical frameworks. This aligns with the conclusions of

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Weyer et al. (2024) regarding the enduring influence of pedagogical knowledge acquired during initial teacher training.
The indicators with the lowest scores—"Adapted content representation to meet the needs and learning styles of diverse learners" (WM = 2.91) and "Anticipated and addressed common student understandings and misconceptions" (WM = 2.86)—indicated areas that required further improvement. These findings support the concerns expressed by Addido et al. (2022), who noted that the complexity and counterintuitive nature of various scientific concepts, such as forces and motion, often lead to students retaining misconceptions unless explicitly addressed. Shaaban et al. (2019) emphasized that pre-service teachers required a profound comprehension of concepts to identify and rectify these errors. Numerous pre-service teachers encountered challenges in facilitating students' comprehension of science accurately, lacking targeted assistance in conceptual change pedagogy and formative assessment strategies.

The results showed that even though science pre-service teachers were good at basic instructional design and pedagogical theory, they still needed to work on their ability to see and fix cognitive barriers in student learning. This gap underscored the imperative for teacher education programs to integrate diagnostic teaching strategies, conceptual change models, and reflective practice into both academic curricula and practical experiences. Carlson and Daehler (2019) argued that pedagogical content knowledge (PCK) must be contextualized and aligned with student cognition, particularly in science education, where misconceptions are both persistent and intricate. If pre-service teachers had been able to get better at these skills, they could have done more than just teach procedures; they could have helped their students become more scientifically literate.

Table 1.3. The Level of Technological, Pedagogical, and Content Knowledge of the Science Pre-service Teachers along Technology Integration into Science Lessons

Indicators	WM	Rank	Interpretation
1. Possesses the technical skills to effectively utilize relevant educational technologies.	2.97	3	Proficient
2. Selects and utilizes appropriate online resources and digital platforms for science instruction.	3.03	1.5	Proficient
3. Troubleshoots technical issues effectively and independently.	2.83	5	Proficient
4. Integrates technology to enhance student learning and engagement in science lessons.	3.03	1.5	Proficient
5. Evaluates and selects teaching technologies aligned with learning objectives and student needs.	2.91	4	Proficient
General Weighted Mean	2.95		Proficient

Table 1.3 showed how much science pre-service teachers knew about using technology in science lessons in terms of Technological, Pedagogical, and Content Knowledge (TPACK). The overall weighted mean of 2.95 showed a "Proficient" level, which meant that the pre-service teachers had shown that they were good at using digital tools and platforms in their teaching. The two highest-rated indicators—"Selected and utilized appropriate online resources and digital platforms for

science instruction" and "Integrated technology to enhance student learning and engagement in science lessons" (WM = 3.03)—demonstrated their ability to leverage available technologies to facilitate student-centered learning. This finding aligned with Memis et al. (2023), which emphasized that pre-service teachers recognized the importance of technology in enhancing instructional effectiveness and student engagement.

Even though these indicators were the lowest-ranked, "Evaluated and selected teaching technologies aligned with learning objectives and student needs" (WM = 2.91) and "Troubleshot technical issues effectively and independently" (WM = 2.83), they still showed that there were gaps in important digital literacy and technical independence. These results were similar to what Yoo and Jin (2024) found. They said that pre-service teachers were often good with technology on the surface, but they didn't have the analytical skills to match tools with different types of learners and teaching goals. Also, the fact that they couldn't fix technical problems on their own very well showed that they needed more training in how to use technology and solve problems on their own—skills that are very important for keeping lessons going in tech-rich classrooms.

The results showed that science pre-service teachers had reached a good level of technology integration, but they were not equally ready in all of the important skills. It was clear that they were comfortable using digital platforms and online resources, but they still needed to work on their ability to critically evaluate tools and solve technical problems. Duan and Exter (2024) emphasize that successful technology integration necessitates operational proficiency, pedagogical insight, and reflective practice. To make science education technology users more flexible and responsive, teacher education programs need to focus on experiential learning, scaffolded digital decision-making, and real-time troubleshooting.

Table 1.4. The Level of Technological, Pedagogical, and Content Knowledge of the Science Pre-service Teachers along Skills in Classroom Management, Assessment, and Differentiation

Indicators	WM	Rank	Interpretation
1. Maintains a well-organized and positive learning environment.	3.09	2	Proficient
2. Adapts teaching methods and materials to meet the diverse learning needs of students.	3.09	2	Proficient
3. Employs a variety of assessment methods to accurately gauge student understanding.	3.03	4.5	Proficient
4. Demonstrates an understanding of diverse learning styles and individual student needs.	3.03	4.5	Proficient
5. Utilizes technology to create differentiated learning activities based on student needs.	3.09	2	Proficient
General Weighted Mean	3.07		Proficient

Table 1.4 showed how well science pre-service teachers knew how to use technology, teach, and test students in the areas of classroom management, assessment, and differentiation. The overall weighted mean of 3.07 showed a "Proficient" level, which meant that the pre-service teachers had shown that they could make lessons that worked for all students and set up learning spaces that worked for everyone.The highest-rated indicators—"Maintained a well-organized and positive learning environment," "Adapted teaching methods and materials to meet the diverse learning needs of students," and "Utilized technology to create differentiated learning activities based on student needs" (WM = 3.09)—showed that they could create fair and responsive

classrooms. These results were in line with Blaz (2023), who said that differentiated instruction and a positive classroom environment were important for getting students to be more involved and do better in science class.

The indicators that got the lowest scores—"Employed a variety of assessment methods to accurately gauge student understanding" and "Demonstrated an understanding of diverse learning styles and individual student needs" (WM = 3.03)—showed that more work needs to be done. Even though they were still considered proficient, these scores showed that pre-service teachers had not yet fully developed their skills in comprehensive assessment literacy or being able to respond to individual learning profiles. Kesawan et al. (2024) noted that effective classroom management must be accompanied by a nuanced understanding of student variability to ensure substantial learning outcomes. Carlson and Daehler (2019) asserted that pedagogical content knowledge (PCK) should include the ability to evaluate student cognition using various assessment techniques, especially in science, where misconceptions and conceptual gaps are prevalent. The results showed that even though science pre-service teachers were good at managing a classroom and adapting lessons to different students' needs, they still needed to work on their ability to accurately assess learning and meet each student's needs. This gap emphasized the imperative for teacher education programs to integrate formative assessment design, reflective practice, and culturally responsive pedagogy into their curricula. Weyer et al. (2024) emphasized that early exposure to diverse assessment tools and student-centered strategies in teacher preparation significantly influenced pedagogical adaptability and enduring instructional effectiveness. If pre-service teachers had been better at these skills, they could have made classrooms that were really different. This means that they not only accepted diversity, but they also used it to help students learn more about science.

Table 1.5. The Level of Technological, Pedagogical, and Content Knowledge of the Science Pre-service Teachers along with **Interplay Among Technology, Pedagogy, and Content**

Indicators	WM	Rank	Interpretation
1. Demonstrates understanding of how technology can transform teaching practices and content representation in science.	2.97	4	Proficient
2. Effectively evaluates the potential and limitations of various technologies in science education.	2.86	5	Proficient
3. Purposefully integrates technology to support learning objectives and enhance student understanding.	3.00	2	Proficient
4. Utilizes technology to enhance students' understanding of complex science concepts.	3.00	2	Proficient
5. Uses technology to facilitate scientific inquiry and problem-solving in the classroom.	3.00	2	Proficient
General Weighted Mean	2.97		Proficient

Table 1.5 showed how much science pre-service teachers knew about how technology, pedagogy, and content work together. The overall weighted mean of 2.97 showed a "Proficient" level, which means that the pre-service teachers were able to use digital tools in ways that were useful for science content and teaching. The indicators that got the best scores—"Purposefully

integrated technology to support learning objectives and enhance student understanding," "Utilized technology to enhance students' understanding of complex science concepts," and "Used technology to facilitate scientific inquiry and problem-solving in the classroom" (WM = 3.00)—showed that they could connect technology to learning goals. These findings correspond with the research conducted by Teknowijoyo et al. (2024), which indicated that teachers equipped with TPACK were more proficient in utilizing technology to facilitate inquiry-based learning and enhance scientific reasoning.

The lowest-ranked indicators—“Demonstrated understanding of how technology can transform teaching practices and content representation in science” (WM = 2.97) and “Effectively evaluated the potential and limitations of various technologies in science education” (WM = 2.86)—identified areas requiring further improvement. These results confirmed the findings of Paidican and Arredondo (2022), who noted that many pre-service teachers did not possess the evaluative skills necessary to critically assess the pedagogical advantages and disadvantages of educational technologies. Without this insight, incorporating technology might have been superficial or misaligned with educational objectives. Furthermore, Cojorn and Sonsupap (2024) argued that authentic TPACK proficiency required not only operational fluency but also reflective discernment in the choice of tools that enrich conceptual depth and cater to learner diversity.

The results showed that even though science pre-service teachers had a good level of TPACK integration, they still didn't fully understand how technology could change things or how to judge things. This gap underscored the imperative for teacher education programs to integrate reflective practice, technology evaluation frameworks, and scenario-based training into their curricula. Mishra and Koehler (2006) initially posited that the efficacy of TPACK derives from the interaction among its three domains, rather than their mere coexistence. If this interaction had been stronger, pre-service teachers could have made science lessons that were more flexible and based on questions, using technology not just as a tool but also as a way to help students learn more deeply.

Table 1.6. The Summary of the Technological, Pedagogical, and Content Knowledge level of the science pre-service teachers

Indicators	WM	rank	Interpretation
1. Depth of Science Knowledge	2.83	5	Proficient
2. Teaching and Learning Principles	2.94	4	Proficient
3. Technology Integration into Science Lessons	2.95	3	Proficient
4. Skills in Classroom Management, Assessment, and Differentiation	3.07	1	Proficient
5. Interplay Among Technology, Pedagogy, and Content	2.97	2	Proficient
Grand Mean	2.95		Proficient

Table 1.6 shows a summary of the science pre-service teachers' levels of technological, pedagogical, and content knowledge. The top rank was "Skills in Classroom Management, Assessment, and Differentiation," with a weighted mean of 3.07, which means that the person was proficient. The second rank, "Interplay Among Technology, Pedagogy, and Content," had a weighted mean of 2.97, which is also seen as proficient. The third rank, "Technology Integration into Science Lessons," had a weighted mean of 2.95, which was also seen as proficient. The fourth rank was "Teaching and Learning Principles," which had a weighted mean of 2.94 and was also

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seen as proficient. The last rank indicator was "Depth of Science Knowledge," which had a weighted mean of 2.83. This is also seen as proficient, even though it was the lowest. The science pre-service teachers' technological, pedagogical, and content knowledge level has a grand mean of 2.95, which means they are proficient. These results showed that the science pre-service teachers have a good mix of knowledge and skills that will help them teach science well. The findings of the current study align with previous research, demonstrating that pre-service teachers possess a high level of proficiency in TPACK. A study at Agusan del Sur State College found a strong link between pre-service teachers' 21st Century Teaching Skills and their high level of TPACK (Soncio et al., 2024). Likewise, a study involving pre-service English as a Foreign Language (EFL) teachers in Turkey revealed that the participants exhibited a generally elevated level of TPACK proficiency (Farhadi & Öztürk, 2023; Genç & Dülger, 2024).

Table 2 presented the extent of Technological, Pedagogical, and Content Knowledge preparedness of the science pre-service teachers as revealed by the assessment of the mentors along mastery of science concepts and principles, breadth of pedagogical strategies, technology integration to science teaching, application of skills in classroom management, assessment, and differentiation, and integration of TPACK into science teaching. This table was interpreted as not prepared, moderately prepared, somewhat prepared, and fully prepared.

Table 2.1. The Extent of Technological, Pedagogical, and Content Knowledge Preparedness of the Science Pre-Service Teachers along with Mastery of Science Concepts and Principles

Indicators	WM	Rank	Interpretation
1. Demonstrates a thorough understanding of science concepts and principles relevant to the grade level.	3.14	1	Moderately Prepared
2. Clearly and accurately explain complex scientific ideas to students.	2.97	3	Moderately Prepared
3. Effectively facilitates hands-on investigations that enhance critical thinking and problem-solving.	2.94	4.5	Moderately Prepared
4. Proactively identifies and addresses common student misconceptions in science.	2.94	4.5	Moderately Prepared
5. Applies scientific knowledge to real-world contexts and examples.	3.06	2	Moderately Prepared
General Weighted Mean	3.01		Moderately Prepared

Table 2.1 showed how well science pre-service teachers were prepared in terms of Technological, Pedagogical, and Content Knowledge (TPACK) and their understanding of science concepts and principles. The overall weighted mean of 3.01 showed that the people who answered were "Moderately Prepared" on all of the indicators that were looked at. The highest-rated item, "Demonstrated a thorough understanding of science concepts and principles relevant to the grade level" (WM = 3.14), indicated that pre-service teachers had gained foundational content knowledge suitable for instructional delivery. Their ability to "Apply scientific knowledge to real-world contexts and examples" (WM = 3.06) also showed that they were getting better at linking abstract ideas to real-life situations, which is an important skill for building scientific literacy (Salinas, 2022). These results were consistent with Long et al. (2019), who highlighted those specific interventions like microteaching and contextualized feedback improved pre-service teachers' comprehension of scientific material.

The indicators with the lowest scores—"Effectively facilitated hands-on investigations that enhance critical thinking and problem-solving" and "Proactively identified and addressed common student misconceptions in science" (WM = 2.94)—showed that there were still gaps in how well teachers used what they learned in the classroom. The respondents exhibited moderate preparedness; however, their inadequate capacity to facilitate inquiry-based learning and identify misconceptions indicated a necessity for enhanced engagement with conceptual change strategies and experiential teaching methodologies. Suprapto (2020) and Guerra-Reyes et al. (2024) observed that misconceptions in science are frequently entrenched and necessitate deliberate instructional design for effective remediation. The results highlighted the necessity of integrating diagnostic teaching, formative assessment, and reflective practice into teacher education programs to enable pre-service teachers to convert their content knowledge into significant, inquiry-based learning experiences.

Table 2.2. The Extent of Technological, Pedagogical, and Content Knowledge Preparedness of the Science Pre-Service Teachers along the Breadth of Pedagogical Strategies

Indicators	WM	Rank	Interpretation
1. Employs various effective instructional strategies appropriate for science teaching.	3.17	1	Moderately Prepared
2. Designs and implements engaging technology-integrated learning experiences.	3.06	3	Moderately Prepared
3. Creates effective learning activities that align with science content standards and learning objectives.	3.11	2	Moderately Prepared
4. Anticipates and addresses potential learning challenges related to specific science content.	2.97	5	Moderately Prepared
5. Adapts instruction based on ongoing assessment of student understanding.	3.03	4	Moderately Prepared
General Weighted Mean	3.07		Moderately Prepared

Table 2.2 showed how well science pre-service teachers were ready to use different teaching methods to teach Technological, Pedagogical, and Content Knowledge (TPACK). The overall weighted mean of 3.07 showed that the people who answered were "Moderately Prepared" on all counts. The highest-rated item, "Employed various effective instructional strategies appropriate for science teaching" (WM = 3.17), showed that the pre-service teachers could use different ways to teach that worked for both science content and the classroom setting. They could "Create effective learning activities that aligned with science content standards and learning objectives" (WM = 3.11), which showed that they knew how to make lessons flow smoothly and fit with the curriculum. These findings align with Weyer et al. (2024), who emphasized that early exposure to pedagogical content in teacher education significantly impacted instructional agility and long-term teaching efficacy.

The lowest-rated indicators—"Anticipated and addressed potential learning challenges related to specific science content" (WM = 2.97) and "Adapted instruction based on ongoing assessment of student understanding" (WM = 3.03)—exposed significant deficiencies in diagnostic and responsive teaching methodologies. The respondents exhibited moderate preparedness; however, their insufficient capacity to foresee conceptual challenges and modify instruction according to formative data indicated a necessity for enhanced engagement with assessment-informed pedagogy. Carlson and Daehler (2019) contended that pedagogical content knowledge should encompass the capacity to interpret student cognition and respond adaptively, especially in science education, where misconceptions endure. To remedy these deficiencies, teacher education programs must integrate scaffolded opportunities for the design of formative assessments, reflective practice, and focused feedback. As Absolor (2023) pointed out, it is important to prepare teachers to meet the changing and diverse needs of science learners by strengthening their pedagogical knowledge through structured intervention.

Table 2.3. The Extent of Technological, Pedagogical, and Content Knowledge Preparedness of the Science Pre-Service Teachers along Technology Integration to Science Teaching

Indicators	WM	Rank	Interpretation
1. Selects and evaluates appropriate technology tools and resources aligned with learning objectives.	3.03	4.5	Moderately Prepared
2. Utilizes technology to represent science content in engaging and innovative ways.	3.14	3	Moderately Prepared
3. Uses technology to actively engage students in the learning process.	3.23	1	Moderately Prepared
4. Effectively uses technology to facilitate scientific inquiry and exploration.	3.17	2	Moderately Prepared
5. Independently troubleshoots minor technical difficulties.	3.03	4.5	Moderately Prepared
General Weighted Mean	3.12		Moderately Prepared

Table 2.3 demonstrated that science pre-service teachers were adequately equipped to incorporate technology into science instruction, achieving a general weighted mean of 3.12. The two indicators that got the most votes were "Used technology to actively engage students in the learning process" (WM = 3.23) and "Effectively used technology to facilitate scientific inquiry and exploration" (WM = 3.17). These results indicated that pre-service teachers possessed a solid understanding of utilizing digital tools to enhance the interactivity and inquiry-based nature of science lessons. This aligned with Teknowijoyo's (2024) findings, which emphasized that technology-enhanced inquiry cultivates the advancement of profound scientific reasoning and engagement among students.

The indicators that scored the lowest, "Selected and evaluated appropriate technology tools and resources aligned with learning objectives" and "Independently troubleshot minor technical difficulties" (both WM = 3.03), showed where things could be better. Pre-service teachers knew how to use technology, but they weren't sure how to choose the right tools or fix simple tech problems. Yoo and Jin (2024) said that being digitally competent means more than just knowing how to use tools. It also means knowing how to match them with learning goals and fix issues. Teacher education programs should put more emphasis on teaching students how to use technology in science classes in a way that is both useful and smooth.

Table 2.4. The Extent of Technological, Pedagogical, and Content Knowledge Preparedness of the Science Pre-Service Teachers along with Application of Skills in Classroom Management, Assessment, and Differentiation

Indicators	WM	Rank	Interpretation
1. Creates an inclusive and equitable learning environment that fosters student success.	3.20	1	Moderately Prepared
2. Designs and implements a variety of assessment strategies to evaluate student learning effectively.	3.09	4	Moderately Prepared
3. Effectively manages classroom resources, materials, and student behavior.	3.00	5	Moderately Prepared
4. Differentiates instruction to meet the diverse learning needs of learners.	3.14	2	Moderately Prepared
5. Uses multiple assessment methods to gain a comprehensive understanding of student learning.	3.11	3	Moderately Prepared
General Weighted Mean	3.11		Moderately Prepared

Table 2.4 demonstrated that science pre-service teachers were moderately prepared to employ skills in classroom management, assessment, and differentiation, yielding a general weighted mean of 3.11. The indicators that got the best scores were "Created an inclusive and equitable learning environment that fostered student success" (WM = 3.20) and "Differentiated instruction to meet the diverse learning needs of learners" (WM = 3.14). These results showed that the pre-service teachers had a strong understanding of inclusive teaching and adaptive instruction. This was in line with what Blaz (2023) said, which was that differentiated instruction helps meet each student's learning needs and makes science classrooms fairer.

The two indicators that got the lowest scores—"Designed and implemented a variety of assessment strategies to evaluate student learning effectively" (WM = 3.09) and "Effectively managed classroom resources, materials, and student behavior" (WM = 3.00)—showed where things could be better. Pre-service teachers appeared to require additional assistance in establishing classroom routines and utilizing various assessment tools, despite being somewhat prepared. Kesawan et al. (2024) noted that effective classroom management and assessment practices are essential for maintaining order and accurately assessing learning. To improve these areas, teacher education programs should include more hands-on training in how to handle classroom dynamics and create formative assessments that help students learn and grow.

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Table 2.5. The Extent of Technological, Pedagogical, and Content Knowledge Preparedness of the Science Pre-Service Teachers along Integration of TPACK into Science Teaching

Indicators	WM	Rank	Interpretation
1. Consistently integrates science content, technology, and effective pedagogical approaches in teaching.	3.20	1	Moderately Prepared
2. Selects and uses technology that enhances teaching methods, content delivery, and student learning.	3.14	2.5	Moderately Prepared
3. Designs technology-integrated learning activities that promote higher order thinking skills.	3.03	4	Moderately Prepared
4. Uses technology to enhance content delivery and increase student engagement and motivation.	3.14	2.5	Moderately Prepared
5. Regularly reflects on their teaching practice, including technology use and determine areas for improvement.	3.00	5	Moderately Prepared
General Weighted Mean	3.10		Moderately Prepared

Table 2.5 indicated that science pre-service teachers were moderately equipped to incorporate Technological, Pedagogical, and Content Knowledge (TPACK) into science instruction, achieving a general weighted mean of 3.10. The most highly rated indicator was "Consistently integrated science content, technology, and effective pedagogical approaches in teaching" (WM = 3.20). This was followed by "Selected and used technology that enhanced teaching methods, content delivery, and student learning" and "Used technology to enhance content delivery and increase student engagement and motivation" (both WM = 3.14). These results showed that pre-service teachers had developed a basic ability to combine scientific content with technology and pedagogy in important ways. This aligns with the findings of Cojorn and Sonsupap (2024), who contended that effective TPACK integration promotes inquiry-based learning and increases student engagement in science classrooms.
The two lowest-rated indicators were "Designed technology-integrated learning activities that promoted higher-order thinking skills" (WM = 3.03) and "Regularly reflected on their teaching practice, including technology use, and determined areas for improvement" (WM = 3.00). These showed that there was still work to be done.

The pre-service teachers were somewhat ready, but they needed more help with creating tasks that were mentally challenging and getting into the habit of thinking about their work. Teknowijoyo (2024) said that higher-order thinking and reflective practice are important for deep learning and making science teaching better all the time. Teacher education programs should thus enhance training in lesson design, the integration of critical thinking, and self-assessment to enable future educators to utilize TPACK not merely functionally, but also transformative.

Table 2.6. The Summary of the Extent of Technological, Pedagogical, and Content Knowledge Preparedness of the science Pre-Service Teachers

Indicators	WM	rank	Interpretation
1. Mastery of Science Concepts and Principles	3.01	5	Moderately Prepared
2. Breadth of Pedagogical Strategies	3.07	4	Moderately Prepared
3. Technology Integration to Science Teaching	3.12	1	Moderately Prepared
4. Application of Skills in Classroom Management, Assessment, and Differentiation	3.11	2	Moderately Prepared
5. Integration of TPACK into Science Teaching	3.10	3	Moderately Prepared
Grand Mean	3.08		Moderately Prepared

Table 2.6 presents the summary of the extent of technological, pedagogical, and content knowledge preparedness of the science pre-service teachers. Data revealed that all indicators were moderately prepared with the grand mean of 3.08. It was found out that among five indicators the top rank was "Technology Integration to Science Teaching" with 3.12 weighted mean. The second rank was "Application of Skills in Classroom Management, Assessment, and Differentiation" with 3.11 weighted mean. Third rank was "Integration of TPACK into Science Teaching" with 3.10 weighted mean. The fourth rank was "Breadth of Pedagogical Strategies" with 3.07 weighted mean. The lowest rank was "Mastery of Science Concepts and Principles" with 3.01 weighted mean. Overall, thi findings suggest that pre-service teachers demonstrate moderate level of preparedness in the essential domains of Technological, Pedagogical, and Content Knowledge. This indicates a promising foundation however they need to enhance their readiness for effective science teaching in technologically enriched environment.

The comprehensive summary reveals that science pre-service teachers are generally moderately prepared across all facets of Technological, Pedagogical, and Content Knowledge (TPACK). This implies that even while they are becoming more proficient with technology, they have an inadequate core understanding of the very subject area they will be teaching. Although a fundamental foundation is in place, more substantial development is required in responsive teaching, efficient assessment, and using technology to foster higher-order thinking, as further supported by the moderate scores in pedagogical strategies, TPACK integration, and classroom management and assessment. In the end, research suggests that improving practical, integrated TPACK abilities and strengthening scientific subject understanding should be given top priority in teacher education programs. Even highly advanced technical or pedagogical strategies may not be sufficient to promote accurate, in-depth learning in future students if they lack a solid understanding of scientific principles.

Table 3. Significant Difference in the level of technological, pedagogical, and content knowledge of the science pre-service teachers between the two groups of respondents

	t_c	α	Df	t_t	Decision	Interpretation
College Instructors vs. Cooperating Teachers	-0.321	0.05	14	±2.145	Accept H_o	No Significant Differences

Table 3 presents the significant difference in the level of technological, pedagogical, and content knowledge of the science pre-service teachers between the two groups of respondents. Data revealed that the computed value of t(t_c) is -0.321, at 5% level of significance. (α) And the degree of freedom is 14, the critical t-value (t_t) is ±2.145. The computed value of t is less than its critical value; thus, the null hypothesis is accepted. Therefore, there is no significant difference among the perceptions of respondents on the level of technological, pedagogical, and content knowledge of the science pre-service teachers. Both the college instructors and cooperating teachers share similar perceptions regarding the TPACK level of the science pre-service teachers. These results implied the consistency and alignment in the evaluation criteria of the two groups; thus, it strengthened the validity of these findings regarding the pre-service teachers' TPACK level.

Table 4. Significant Difference in the extent of preparedness of the science pre-service teachers between the assessments of the two groups of respondents

	t_c	α	Df	t_t	Decision	Interpretation
College Instructors vs. Cooperating Teachers	0.167	0.05	14	±2.145	Accept H_o	No Significant Differences

Table 4 presents the significant difference in the extent of preparedness of the science pre-service teachers between the assessments of the two groups of respondents- college instructors and cooperating teachers. Data revealed that the computed value of t (t_c) is 0.167, at 5% level of significance. (α) And the degree of freedom is 14, the critical t-value (t_t) is ±2.145. The computed value of t is less than its critical value; thus, the null hypothesis is accepted. Therefore, there is no significant difference among the perceptions of respondents on the extent of preparedness of the science pre-service teachers. Therefore, both groups of respondents share a consistent perception of the extent of technological, pedagogical, and content knowledge preparedness of the science pre-service teachers. This finding supports the reliability and consistency of the evaluations of the two groups of respondents and suggests a common understanding of the competencies demonstrated by the pre-service teachers across the assessed indicators.

DISCUSSION

The study's results showed that the pre-service science teachers at Calabanga Community College had a good level of Technological, Pedagogical, and Content Knowledge (TPACK) overall. Their readiness to teach science well, on the other hand, was only rated as moderate. They were

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good at things like managing a classroom and making sure everyone got the same amount of work, but they had trouble with inquiry-based instruction, formative assessments, and using adaptive technologies. These findings indicated that while foundational knowledge existed, the capacity to implement it in dynamic, student-centered learning environments necessitated additional development.

Mentor evaluations, sourced from both college instructors and cooperating teachers, revealed no significant discrepancies, suggesting a consensus regarding the pre-service teachers' strengths and weaknesses. This consistency made the assessment more reliable and showed that we need to work together to improve instructional readiness.
The results were in line with what other studies had found about the same gaps in teacher training. Memis et al. (2023) and Laius & Pressman (2024) discovered that although pre-service teachers frequently possessed robust content knowledge, they encountered difficulties in incorporating technology in pedagogically significant manners. Duan & Exter (2024) contended that digital fluency should encompass not only fundamental tool utilization but also critical assessment and alignment with educational objectives—domains in which study participants exhibited moderate competence. It was hard to deal with students' misunderstandings and create assessments that were different for each student. This was similar to what Suprapto (2020) and Carlson & Daehler (2019) found, who stressed how important diagnostic teaching and pedagogical content knowledge are in science education.
The study made it clear that teacher education programs need to have specific interventions. The proposed STEP-UP (Science Teacher Empowerment Program – Uplifting Potential) sought to rectify these deficiencies through workshops, peer evaluation, and experiential learning centered on conceptual fluency, instructional adaptability, and reflective technology integration. This method provided a feasible strategy for improving TPACK skills and ensuring that teacher training meets the needs of 21st-century science education.

Although the study made valuable contributions, it was constrained by its sample size and geographical focus, concentrating exclusively on mentors from Calabanga Community College and adjacent high schools. There may have been bias because the data came from self-reports, and the descriptive design didn't let us figure out what caused what. Moreover, the absence of classroom observations and longitudinal tracking constrained the analytical depth. Future research could improve its findings by utilizing larger samples, mixed-method approaches, and longitudinal designs to accurately document the progression of TPACK competencies over time.

Conclusion

This study examined the Technological, Pedagogical, and Content Knowledge (TPACK) of pre-service science teachers at Calabanga Community College and evaluated their preparedness for effective science instruction. The results showed that the participants had a good level of TPACK in all five areas: science content knowledge, pedagogical principles, technology integration, classroom management, and the relationships between TPACK elements. However, they were only moderately ready to teach. They had a lot of trouble with inquiry-based instruction, formative assessments, and adaptive technologies in particular.
The minimal differences between the evaluations of college instructors and cooperating teachers indicated a consensus on the pre-service teachers' competencies, thereby improving the assessment's reliability. These findings indicated that organized interventions are necessary to

bridge the disparity between individuals' knowledge and its practical application. In response, the study proposed the STEP-UP (Science Teacher Empowerment Program – Uplifting Potential), a professional development framework designed to enhance conceptual fluency, instructional responsiveness, and reflective technology integration. The program emphasized experiential learning, peer feedback, and scaffolded inquiry to enhance TPACK skills in authentic teaching contexts.

Because of the study's limitations and scope, it is best for future research to use a bigger sample size and follow TPACK development over time during the internship phases. Mixed-method approaches that incorporate classroom observations and student performance data would enhance our understanding of the impact of TPACK on instruction. Moreover, teacher education institutions may consider incorporating reflective practice, formative assessment design, and technology evaluation frameworks into their curriculum to ensure that pre-service teachers are not only proficient in theory but also adaptable and responsive in practice.

REFERENCES

Abdulbakioglu, M., Kolushpayeva, A., Balta, N., Japashov, N., & Bae, C. L. (2022). Open Lesson as a Means of Teachers' Learning. Education Sciences, 12(10), 692. https://doi.org/10.3390/educsci12100692

Absolor, J. L. (2023). Pedagogical Knowledge of the Pre-Service Teachers of Ilocos Sur Polytechnic State College: A Framework for Intervention Plan. *International Journal of Social Science Research and Review*, *6*(6), 648-665. https://doi.org/10.47814/ijssrr.v6i6.1438

Adu Gyamfi, K. (2020). Pre-Service Teachers' Conception of an Effective Science Teacher: The Case of Initial Teacher Training. Journal of Turkish Science Education, 17 (1), 40-61.

Alghamdi, A. A. (2022). Exploring Early Childhood Teachers' Beliefs About STEAM Education in Saudi Arabia. Early Childhood Education Journal, 51(2), 247–256. https://doi.org/10.1007/s10643-021-01303-0

Alhabai, HH. (2017) Technological Pedagogical Content Knowledge (TPACK) Effectiveness on English Teachers and Students in Saudi Arabia. Retrieved from: https://digscholarship.unco.edu/cgi/viewcontent.cgi?article=1457&context=dissertations

Antonio, R. P. (2024). Promoting Technological Pedagogical Content Knowledge (TPACK) in Preservice Science Teacher Education: A Scoping Review of Instructional Strategies, Interventions, and Programs. International Journal on Studies in Education, 157–171. https://doi.org/10.46328/ijonse.302

Azizah, D. S., Putri, D. A., & Mulhayatiah, D. (2021). Prospective Science Teacher TPACK Skills in Preparing the Lesson Plans. 8(2), 132–139. https://doi.org/10.31258/JGS.8.2.132-139

Berie, A. M. (2022). Inquiry-Based Learning Implementation: Students' Perception and Preference. ResearchGate

Blaz, D. (2023). Differentiated Instruction. https://doi.org/10.4324/9781315695648

Busch, K., Kudumu, M., & Park, S. (2022). Pedagogical Content Knowledge for Informal Science Educators: Development of the ISE-PCK Framework. Research in Science Education, 53(2), 253–274. https://doi.org/10.1007/s11165-022-10055-9

Carlson, J., & Daehler, K. (2019). The refined consensus model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77-92). Springer.

Cents-Boonstra, M., Lichtwarck-Aschoff, A., Denessen, E., & Arends, L. R. (2020). Fostering student engagement with motivating teaching: An observation study of teacher and student behaviours. Teaching and Teacher Education, 92, 103099

Chan, J., & Erduran, S. (2022). The Impact of Collaboration Between Science and Religious Education Teachers on Their Understanding and Views of Argumentation. Research in Science Education, 53(1), 121–137. https://doi.org/10.1007/s11165-022-10041-1 Costa, A., Loureiro, M., & Ferreira, M. E. (2021). Scientific Literacy: The Conceptual Framework Prevailing over the First Decade of the Twenty-First Century. Revista Colombiana De Educación, 1(81). https://doi.org/10.17227/rce.num81-10293

Commission on Higher Education, 2020. 'New normal policies and guidelines on the deployment of pre-service teachers for field study and teaching internship for AY2020-2021', viewed 21 April 2022,
(1) (PDF) Science Pre-service Teachers' TPACK, Readiness, Self-Efficacy, and Challenges Toward Online Teaching Internship. Available from: https://www.researchgate.net/publication/381190568_Science_Pre-service_Teachers'_TPACK_Readiness_Self-Efficacy_and_Challenges_Toward_Online_Teaching_Internship [accessed Nov 03 2024].

Craig, A. (2017). The Importance of TPACK and Why I am Drawn to It. Retrieved from: https://medium.com/@AJ_Craig/the-importance-of-tpack-868c0ee44fc6

Curriculum Development Division. (2015). PISA National Report. Ministry of Education Malaysia.

Darsih, E., Agustiana, V., Rahmatunisa, W., & Hanggara, A. (2024). Factors affecting preservice English teachers' technological pedagogical content knowledge (tpack). Indonesian Journal of Learning and Instruction, 7(2). https://doi.org/10.25134/ijli.v7i2.10943

Davis, E. A., & Palincsar, A. S. (2022). Engagement in high-leverage science teaching practices among novice elementary teachers. Science Education, 107(2), 291–332. https://doi.org/10.1002/sce.21766

Dawson, K., & Ritzhaupt, A. D. (2014). Using lesson plans as a proxy for teacher technology integration practices in math and science using TPACK: A transferrable research design. 2014(1), 1398–1404. https://www.learntechlib.org/primary/p/130962/

Demirel, M., & Caymaz, B. (2015). Prospective Science and Primary School Teachers' Selfefficacy Beliefs in Scientific Literacy. Procedia - Social and Behavioral Sciences, 191, 1903–1908. https://doi.org/10.1016/j.sbspro.2015.04.500

Duan, L., & Exter, M. (2024). Pre-service teachers' development of TPACK in technology-rich environments. *Journal of Digital Learning in Teacher Education*. https://doi.org/10.1080/10476210.2024.2307844

Duncan, R. G., Av-Shalom, N. Y., & Chinn, C. A. (2021). Inquiry and Learning in Science (pp. 325–344). Routledge Handbooks Online. https://doi.org/10.4324/9781315685779-22

Earle, R. S. (2002). The integration of instructional technology into public education: Promises and challenges. *Educational Technology*, *42*(1), 5-13.

Espinosa, R. C. et. al (2024). *Science Pre-service Teachers' TPACK, Readiness, Self-Efficacy, and Challenges Toward Online Teaching Internship. Jurnal Penelitian dan Pembelajaran IPA. Vol.10, No.1, 2024, p. 63-77*

Espinosa, R. J. B., et al. (2024). Science pre-service teachers' TPACK, readiness, self-efficacy, and challenges. *Jurnal Penelitian dan Pembelajaran IPA*, *10*(1), 63–77. https://www.researchgate.net/publication/378514115_Science_Pre-Service_Teachers%27_TPACK_Readiness_Self-Efficacy_and_Challenges

Frontiers in Education. (2025). The rise and drop of online learning: adaptability and future prospects. Frontiers in Education, 10, Article 1522905. (Note: This is a specific article within the journal, relevant to challenges and adaptability.)

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 28-42). Routledge Press.

Ginting, D., & Linarsih, A. (2022). Teacher professional development in the perspective of technology pedagogical content knowledge theoretical framework. Jurnal Visi Ilmu Pendidikan, 14(1), 1. https://doi.org/10.26418/jvip.v14i1.49334

Goldhaber, D., Strunk, K. O., Brown, N., Naito, N., & Wolff, M. (2020). Teacher staffing challenges in California: Examining the uniqueness of rural school districts. *AERA Open*, 6(open in a new window)(3(open in a new window)), 233285842095183. https://doi.org/10.1177/2332858420951833

Guerra-Reyes, F., Guerra-Dávila, E., Naranjo-Toro, M. E., Basantes-Andrade, A., & Guevara-Betancourt, S. (2024). Misconceptions in the Learning of Natural Sciences: A Systematic Review. Neveléstudomány. https://doi.org/10.3390/educsci14050497

Hardinata, A., & Putri, R. E. (2019). Implementation of scientific literacy competencies PISA framework 2015 through lesson study: teacher knowledge and result discussion. Journal of Physics: Conference Series, 1317, 012211. https://doi.org/10.1088/1742- 6596/1317/1/012211

Ingersoll, R. M., & Tran, H. (2023). Teacher shortages and turnover in rural schools in the US: An organisational analysis. *Educational Administration Quarterly*, 59(open in a new window)(2(open in a new window)), 396–431. https://doi.org/10.1177/0013161X231159922

Jimenez, P. C., Golick, D., Couch, B. A., & Dauer, J. M. (2022). Developing and evaluating a pollination systems knowledge assessment in a multidisciplinary course. International Journal of STEM Education, 9(1). https://doi.org/10.1186/s40594-022-00368-6

Juhji, J., & Nuangchalerm, P. (2020). Interaction between scientific attitudes and science process skills toward technological pedagogical content knowledge. *Journal for the education of gifted young scientists, 8*(1), 1-16. https://doi.org/10.17478/ jegys.2020.XX

Kesawan, P., Nur, K., & Rosmidar, R. (2024). Keterampilan Mengelola Kelas. 2(1), 307–315. https://doi.org/10.62383/edukasi.v2i1.1040

Kesawan, P., Nur, K., & Rosmidar, R. (2024). Keterampilan Mengelola Kelas. 2(1), 307–315. https://doi.org/10.62383/edukasi.v2i1.1040

Koehler, M. (2019). *TPACK 101*. [Web page]. Retrieved from http://www.matt-koehler.com/tpack-101/

Koehler, Matthew. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. Teachers College REcord. 108. 1017-1054. 10.1111/j.1467-9620.2006.00684.x.

Laius, M., & Pressman, H. (2024). Cultivating preservice science teachers' TPACK and self-efficacy. *Journal of Science Education*. https://doi.org/10.1007/s10972-024-09943-4

Lekhu, M. A. (2023). Pre-Service Science Teachers' Preparedness for Classroom Teaching: Exploring Aspects of Self-Efficacy and Pedagogical Content Knowledge for Sustainable Learning Environments. Journal of Curriculum Studies Research, 5(1), 113-129. https://doi.org/10.46303/jcsr.2023.9

Luft, J. A., Navy, S. L., Wong, S. S., & Hill, K. M. (2022). The first 5 years of teaching science: The beliefs, knowledge, practices, and opportunities to learn of secondary science teachers. Journal of Research in Science Teaching, 59(9), 1692–1725. https://doi.org/10.1002/tea.21771

Memis, S., Yildiz, A., & Kaya, F. (2023). Exploring the relationship between pre-service teachers' TPACK and blended teaching readiness. *Education and Information Technologies*. https://doi.org/10.1007/s10639-023-11850-8

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *Teachers College Record*, *108* (6), 1017–1054

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054. https://www.tcrecord.org/Content.asp?ContentID=12591

Mouza, C., Mead, H., Alkhateeb, B., & Pollock, L. (2022). A Virtual Professional Development Program for Computer Science Education During COVID- 19. TechTrends, 66(3), 436–449. https://doi.org/10.1007/s11528-022-00731-y

Nithitakkharanon, P., Vetsawat, C., Sawasdee, V., & Nuangchalerm, P. (2023). Fostering TPACK for Pre-service Teachers about Learning Management Competency into Professional Experiences. Journal of Curriculum and Teaching, 12(1), 220. https://doi.org/10.5430/jct.v12n1p220

Olszewski, B., & Crompton, H. (2020). Educational technology conditions to support the development of digital age skills. Computers and Education, 150, 103849.

Paidican, M. A., & Arredondo, P. A. (2022). The technological-pedagogical knowledge for in-service teachers in primary education: A systematic literature review. Contemporary Educational Technology, 14(3), 370. https://doi.org/10.30935/cedtech/11813

Ramos, R, Babasa, E, Vergara, I,Manalo, B, Guppy, L, & Morfi, (2020) 'The TPACK confidence ofpre-service teachers in selectedPhilippine teacher educationinstitutions', International Journalof Education, Psychology andCounselling, vol. 5, no. 37, pp.196-205 *(1) (PDF) Science Pre-service Teachers' TPACK, Readiness, Self-Efficacy, and Challenges Toward Online Teaching Internship*. Available from: https://www.researchgate.net/publication/381190568_Science_Pre-service_Teachers'_TPACK_Readiness_Self-Efficacy_and_Challenges_Toward_Online_Teaching_Internship [accessed Nov 03 2024].

Salinas, J. (2022). Inquiry-based science methods and content mastery in teacher education. *Frontiers in Education*. https://doi.org/10.3389/feduc.2022.951566

Santos, J.M. & Castro, R. D.R. (2021). Technological Pedagogical content knowledge (TPACK) in action: Application of learning in the classroom by pre-service teachers (PST). Bulacan State University. Bulacan, Philippines

Sari, D., & Wulandari, R. (2022). Challenges and strategies in implementing inquiry-based science instruction. *ERIC Journal*. https://files.eric.ed.gov/fulltext/EJ1342654.pdf

Seema, P. V. (2024). Developing scientific literacy to promote 21st century skills. Journal on School Educational Technology, 20(1), 1. https://doi.org/10.26634/jsch.20.1.21018

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher*, *15* (2), 4–14. http://dx.doi.org/10.3102/0013189×015002004

Siregar, M., Tan, R., & Villanueva, J. (2024). The TPACK confidence of pre-service teachers in selected Philippine teacher education institutions. *International Journal of Education, Psychology and Counseling*. https://ijecp.ikop.org/index.php/ijecp/article/view/294

Soncio, M. S., Bairoy, D. M., & Repollo, J. L. (2024). The Effect of TPACK on Developing 21st-Century Teaching Skills: A Pre-Service Teacher's Perspective. International Journal of Research and Innovation in Social Science, VIII(IX), 1804–1815. https://doi.org/10.47772/ijriss.2024.8090148

Starkey, L. (2019). A review of research exploring teacher preparation for the digital age. Victoria Universty of Wellington, Kelburn, Wellington, New Zealand. https://doi.org/10.1080/0305764X.2019.1625867

Suprapto, N. (2020). Do We Experience Misconceptions?: An Ontological Review of Misconceptions in Science. 1(2), 50–55. https://doi.org/10.46627/SIPOSE.V1I2.24

Suprapto, N. (2020). Do we experience misconceptions?: An ontological review of misconceptions in science. *Studies in Philosophy of Science and Education*, *1*(2), 50–55. https://jurnal.untirta.ac.id/index.php/SiPoSE/article/view/9769

Tanak, A. (2020). Promoting higher-order thinking through inquiry-based science activities. *International Journal of Education in Mathematics, Science, and Technology*. https://files.eric.ed.gov/fulltext/EJ1277123.pdf

Teknowijoyo, F. (2024). Exploring the Role of TPACK in Promoting Inquiry-based Learning in 21. KnE Social Sciences. https://doi.org/10.18502/kss.v9i2.14925

Tugelbayeva, T., Eleupanovna, Z. A., Tokkulova, G., Nizamova, M. & Kulzhanovna, Y A. (2020). Problems of preservice teachers on technological pedagogical knowledge skills. World Journal on Educational Technology: Current Issues. 12(4), 361-372. https://doi.org/10.18844/wjet.v12i4.5189

UNESCO. (2002). Information and Communication Technologies in Teacher Education: A Planning Guide. Paris, France: UNESCO

Vlachos, I., Stylos, G., & Kotsis, K. T. (2024). Primary school teachers' attitudes towards experimentation in physicsteaching. European Journal of Science and Mathematics Education, 12(1), 60–70. https://doi.org/10.30935/scimath/13830

Walag, Angelo Mark & Fajardo, Maria Teresa & Guimary, Faith & Bacarrisas, Prosibeth. (2020). Science Teachers' Self-Efficacy in Teaching Different K to 12 Science Subjects: The Case of Cagayan de Oro City, Philippines. Science International. 32. 587-592.

Wangchuk, S., Wangdi, D., Tshomo, S., & Dorji, U. (2023). Pre-service Science Teachers' Conceptions of the Nature of Science. Освіта, Інноватика, Практика, 6. https://doi.org/10.17102/eip.6.2023.02

Winter, R., Lee, M., & Santos, D. (2021). Technological pedagogical content knowledge and emergency remote teaching. In *De La Salle University Research Congress*. De La Salle University. https://www.dlsu.edu.ph/wp-content/uploads/pdf/conferences/research-congress-proceedings/2021/LCS/LCS-I-006.pdf

Yassin, M. K. (2024). Technology Integration in Learning Ecosystems (pp. 73–86). IGI Global. https://doi.org/10.4018/979-8-3693-4103-2.ch004

Yildiz, H. (2019). Examining the acceptance and use of online social networks by preservice teachers within the context of unified theory of acceptance and use of technology model. Journal of Computing in Higher Education, 31, 173-209. https://doi.org/10.1007/s12528-018-9200-6

Yoo, M., & Jin, S.-H. (2024). Needs Analysis of Pre-service Teachers for Digital Competence. 교육발전, 44(2), 391–406. https://doi.org/10.34245/jed.44.2.391