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Pedagogical Content Knowledge (PCK) of Prospective Science Teachers in ASEAN to Realize Sustainable Development Action

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ABSTRACT

Prospective science teachers must master pedagogical knowledge (PK) and content knowledge (CK), commonly referred to as Pedagogical Content Knowledge (PCK), before entering the teaching profession. PCK is essential professional knowledge that supports effective science teaching. This study aims to analyze the PCK readiness of prospective science teachers in Indonesia and the Philippines, with a focus on the CK and PK competencies required for teaching in the ASEAN context. The study employed a mixed-methods approach. Survey data were collected from 110 prospective science teachers undertaking field teaching practice in schools in Indonesia and the Philippines. In addition, in-depth interviews were conducted with 12 participants, consisting of six prospective teachers from each country. The data focused on participants' understanding and preparation related to pedagogical skills and science subject matter. The results indicate that the overall PCK level of prospective science teachers falls within the "moderately ready" category. However, the proportion of participants classified as "ready" remains relatively low, ranging from 44.9% to 58.5%. These findings suggest a need for strengthening both PK and CK among prospective science teachers. Enhancing PK can be achieved through additional pedagogical education and targeted training programs to improve teaching skills. Meanwhile, improving CK can be supported by providing more specialized science content courses aligned with school curricula prior to teaching practice. PCK readiness plays a crucial role in supporting sustainable development. Beyond integrating pedagogy and content, PCK enables prospective teachers to effectively convey scientific concepts related to sustainability issues: including climate change, natural resource conservation, and environmentally friendly technologies.

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INTRODUCTION

21st century science education requires prospective teachers not only to master the material, but also to be able to integrate content knowledge (CK) and pedagogical knowledge (PK) in meaningful, innovative, and sustainability-oriented learning according to the SDGs agenda. However, the readiness of prospective teachers in this integration is still relatively low. Today's learning centers on student-centered learning that emphasizes mastery of the process through activities and practicums, along with the dynamic development of science and technology. Teachers are required to be creative and adaptive because future challenges are uncertain, so learning 21st century skills is the main key. This is in accordance with the theory that the challenge to prepare for the future life is with learning 21st century skills where children will be faced with uncertain situations in the future (Hong et al., 2019). Uncertainty in the future is related to the material that students will receive that is always changing and evolving. The changes in the material that students receive must be in line with changes in the way a teacher teaches. If the change of material is taught in the way of teaching in the past, for example lectures, then students will not understand and learning does not make students actively search for the material themselves.

Pedagogical Content Knowledge (PCK) is a teacher's knowledge that integrates pedagogy and content explicitly (Shulman, 1987; Khasanah & Wilujeng, 2025), which consists of Content Knowledge (CK) and Pedagogical Knowledge (PK). CK describes mastery of teaching materials as the main requirement to become a teacher, while PK includes mastery of learning practices, strategies, procedures, and methods (Shulman, 1987; Khasanah & Wilujeng, 2025). PCK plays an important role in helping students understand difficult concepts as well as improve critical thinking, creativity, communication, and collaboration skills (Cetin-Berber & Erdem, 2015).

Pedagogical knowledge includes mastery of student characteristics, learning theories and principles, curriculum development, instructional activities, student potential development, communication, as well as assessment and evaluation. Pedagogical competence consists of ten standards, namely mastery of student characteristics, understanding of learning theories, curriculum development, professional development activities, utilization of technology as learning

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media, provision of facilities to support student potential development, effective and empathetic communication, implementation of assessment and evaluation, utilization of evaluation results, and reflective action to improve the quality of teaching and learning (Ministry of National Education of Indonesia, 2007). In the Philippines, teachers are required to possess pedagogical competence aligned with 21st-century education demands, which are organized into seven main domains. These include mastery of content knowledge and its relevance across curriculum areas, creation of a safe and inclusive learning environment, responsiveness to learner diversity, alignment with national and local curricula, implementation of varied assessment strategies, establishment of school–community partnerships, and continuous professional development while upholding professional values such as care, respect, and integrity (Philippine DepEd Order No. 42, s. 2017).

A good teacher is one who can involve students in all learning activities in the classroom. Teachers must understand the 10 pedagogic competency standards so that learning activities are more meaningful. PCK is knowledge about the relationship between pedagogy and learning materials that will be given to students. PCK is a basic ability for teacher capacity development. The development of teachers in Indonesia is supported by teacher professional education (PPG) that must be taken by education graduates. Teachers are expected to develop into professions that can support 21st century skills and the development of technological advances by creating quality students. The concept of teacher education focuses on technology education that is integrated in PCK or pedagogical content knowledge (Shulman, 1986). Learning practices use PCK to acquire the knowledge and skills students need that are relevant to content, culture, context and psychological roles (Denby, D, and Holman, J , 2002). PCK is a science that is very helpful for teachers to create a meeting point between the material that will be delivered at school, the content of learning, and pedagogic competence. Nuangchalerm (2020) shows that PCK can help teachers learn to be good at teaching and better understand pedagogical skills. Teachers who already know the content of the material must think about what learning model is suitable for use in learning activities so that all students can be active.

Science is a material that really needs a variety of learning models to make students understand the material. Prospective science teachers must be able to understand pedagogical skills and use these skills to teach a wide variety of science materials. The readiness of prospective teachers in terms of PCK will be very important to be known to be able to find problems related

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to this. This research will be very important to produce conclusions related to the condition of prospective science teachers in Indonesia and the Philippines to find out PCK. According to Shulman (1987), teacher preparation programs must combine pedagogical knowledge and content knowledge to teach and learn appropriately. PCK is the ability to combine knowledge of a certain discipline with science teaching. This makes the teacher really understand the content and turn it into appropriate teaching (Shulman, 1987). Students who are interested in learning activities will also start to be interested in learning the material. The combination of fun learning activities and the material taught will be easily accepted by students if their hearts are happy.

Heibert et al (2007) propose a teacher preparation framework to help develop teacher competence in setting learning goals, evaluating student performance, hypothesizing the relationship between learning materials and self-reflection teaching. Social changes and learning environments are driving the trend of PCK to higher levels of use (Nuangchalerm, 2020). PCK, as the integration of pedagogy and content, is a fundamental competence for prospective teachers' professionalism, and this study analyzes PCK in ASEAN education as input for Teacher Professional Education programs in Indonesia and the Philippines as well as for universities in integrating PCK into coursework. The conceptual foundation of PCK was introduced by Shulman (1987) and further developed into TPCK by Koehler and Mishra (2019) through the integration of technology supports prospective teachers in integrating up-to-date content and technology into classroom learning. The effective interaction between pedagogical skills and content supports innovative, effective, and enjoyable learning and is essential for prospective teachers' professional readiness.

The urgency of strengthening PCK is closely aligned with the global education agenda, particularly the Sustainable Development Goals (SDGs) launched by the United Nations to achieve inclusive, sustainable, and environmentally sound development (Kleespies & Dierkes, 2022; Whittingham et al., 2023). SDGS no. 4 emphasizes the importance of quality education for all. SDGs oriented education aims to equip students with knowledge, skills, values, and attitudes related to global issues such as climate change, gender equality, social justice, and environmental conservation. The implementation of SDGs in learning requires the central role of teachers through pedagogical content knowledge (PCK) readiness, which includes content mastery, pedagogical strategies, understanding student characteristics, and the ability to design learning and evaluation based on SDGs issues.

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The readiness of teachers' PCK is a crucial aspect because not all teachers have adequate competence and experience in integrating the SDGs into learning tools. For this reason, training and professional development for teachers are necessary steps. This training must include an in-depth understanding of the SDGs, innovative teaching strategies, and assessment techniques that support SDGs-based learning. Thus, teachers can be more confident and skilled in designing learning that not only prioritizes academic achievement, but also shapes the character of students with a global perspective.

A number of previous studies have emphasized the importance of Pedagogical Content Knowledge (PCK) as the foundation of teacher professionalism (Shulman, 1987; Cetin-Berber & Erdem, 2015). Studies at the local level also show variations in the readiness of prospective teachers in mastering aspects of PCK, both in terms of pedagogy and scientific content (Nuangchalerm, 2020; Tondeur et al., 2017). However, the study generally still focuses only on technology integration or on one particular discipline and not many have conducted a comparative analysis across ASEAN countries. This study aims to analyze the readiness of prospective science teachers in Indonesia and the Philippines regarding their Pedagogical Content Knowledge (PCK) in the context of SDGs implementation.

RESEARCH METHOD

This study will use the research design of the explanatory sequential mixed method. The design of the sequential mixed method of explanation (also called the two-phase model). J. W. Creswell & Clark (2017) consists of first quantitative data collection and then qualitative data collection to help explain or elaborate the quantitative results. The reason for this approach is that the quantitative data and results provide an overview of the research problem; Further analysis, particularly through qualitative data collection, is necessary to refine, expand, or explain the general quantitative picture (Creswell, J., & Guetterman, 2018). The research subjects amounted to 110 prospective science teachers (41 Indonesians, 69 Filipinos) who were selected using purposive sampling techniques. They come from various universities in the Philippines and Indonesia that offer science education programs. Universities in Indonesia use 2 universities and Philippines uses 3 universities. Students who are considered respondents are students in semesters 5 to 7 who are or have been practicing teaching at school for 1 semester. The quantitative and qualitative instrument was developed based on the framework of PCK Shulman (1987), validated through

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expert judgment by 2 lecturers of education experts. The lecturers who are asked to validate are education and evaluation experts.

The analysis will be carried out in such a way that quantitative research is carried out first and then qualitative research will follow. The quantitative stage is carried out first by distributing the questionnaire online through Google Form, which can be accessed using the account of the respective university institution. Data collection lasted for three weeks. The qualitative stage is carried out after the quantitative results are analyzed. A total of 12 participants (6 from Indonesia and 6 from the Philippines) were selected based on the highest, medium, and lowest readiness categories. Interviews are conducted in a semi structured manner via the Zoom platform in English or local languages according to the participants' convenience, with a duration of 30–45 minutes per session. All interviews were recorded and transcribed.

Qualitative analysis was carried out using a thematic analysis approach based on the steps of Braun & Clarke (2006): (1) read the transcript in depth, (2) do initial coding, (3) group the code into themes, (4) review and refine the theme, and (5) interpret the meaning in the context of quantitative results. Data analysis was carried out with SPSS with Independent Sample T-Test for quantitative and manual coding with a thematic matrix for qualitative.

RESULT

Table 1 shows that 85.4% of Indonesian students and 60.9% of Filipino students who are prospective science teachers demonstrate readiness in pedagogical skills, while 14.6% of Indonesian and 37.7% of Filipino students are in the fairly ready category, and only 1.4% of Filipino students are categorized as not ready to master pedagogical knowledge. This fairly ready category shows that students have not mastered too many indicators that must be achieved in Pedagogy. The average scores obtained from the questionnaire were determined and grouped into four categories, namely unprepared, adequately prepared, prepared, and very prepared. The interpretation of the score used an updated scale, i.e. a score ≤ 1.49 was categorized as unprepared, a score of 1.50–2.49 as moderately prepared, a score of 2.50–3.49 as ready, and a score of ≥ 3.50 as very prepared. This scale is used to more accurately describe the level of readiness of respondents based on the measurement results.

Table 1. Level of PK (Pedagogical Knowledge)

Level of Readiness	Philippines		Indonesia	
	F	%	F	%
Ready	42	60.9	35	85.4

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Level of Readiness	Philippines		Indonesia	
Moderately Ready	26	37.7	6	14.6
Not Ready	1	1.4	0	0
N=	69	100.0	41	100.0

The pedagogical knowledge assessed in this study is to see how to assess student performance in the classroom, how to teach, teaching style for diverse students, how teachers use various teaching approaches, how to overcome student misunderstandings, how to manage the classroom, and how to adapt the learning approach to the student's condition. The readiness of prospective Indonesian teachers is higher than that of the Philippines countries. This was supported by the research of Lestari & Rahayu (2023), who found that preservice science teachers in Indonesia possessed a high level of pedagogical knowledge for teaching science.

Table 2 shows that 53.6% of Indonesian and 51.2% of Filipino prospective science teachers are ready in science content knowledge, while 48.8% of Indonesian and 43.5% of Filipino students are fairly ready, and only 2.9% of Filipino students are not ready. This category of quite ready shows that students have not mastered the indicators that must be achieved in science knowledge material. The knowledge of the content of science material assessed in this study is that students have sufficient knowledge of physics, chemistry, biology. The second indicator is that students can integrate SETS (Science, Environment, Technology, and Society) in classroom learning. The third indicator is that students can match science material with the learning approach they want to use. The fourth indicator is that students can apply contextual learning, namely presenting science in real life. The fifth indicator is that students can apply their knowledge in the fields of Physics, Chemistry, and Biology and slice it into classroom learning. The eighth indicator is that students have extensive knowledge that is currently taught, namely biophysics, biochemistry, environmental balance, plants, animals, global warming.

Table 2. Level of CK (Content Knowledge)

Level of Readiness	Philippines		Indonesia	
	F	%	F	%
Ready	37	53.6	21	51.2
Moderately Ready	30	43.5	20	48.8
Not Ready	2	2.9	0	0
N=	69	100.0	41	100.0

Table 2 above also explains about students who belong to the unprepared group. There were 2 students from the Philippines while from Indonesia there were no students who were included in the unprepared category. The lack of pedagogy means that students do not know much about what science materials must be taught to students at school. In addition, they also lack

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understanding of the latest and current material that must be mastered if they want to become science teachers.

Table 3 shows that 44.9% of Indonesian and 58.5% of Filipino prospective science teachers are ready in both pedagogical and content knowledge, while around 41–49% are moderate ready and only 5.8% of Filipinos are not ready. This category of sufficient readiness indicates that students have not mastered the indicators that must be achieved in the PCK assessment. The things assessed in this study include how students choose an effective teaching approach to guide students' thinking and learning on science materials, how to choose different learning models to teach various topics on science materials, and how to choose different learning methods to teach various topics in science materials.

Table 3. Level of PCK (Pedagogical Content Knowledge)

Level of Readiness	Philippines		Indonesia	
	F	%	F	%
Ready	31	44.9	24	58.5
Moderately Ready	34	49.3	17	41.5
Not Ready	4	5.8	0	0
N=	69	100.0	41	100.0

Based on qualitative data in terms of classroom management, there are still real challenges. The first respondent said that it was difficult to manage the class directly because they were not used to it. The second respondent stated:

"When the material explanation took place, there were students who fell asleep... I'm still overwhelmed."

This reflects that preservice teachers still do not have the capacity to intervene appropriately and professionally when dealing with unproductive behavior. They tend to still depend on teachers to solve discipline problems. The pedagogical readiness of prospective science teachers is still in the early stages of development. Although they showed enthusiasm and some early strategies, there were still significant challenges especially in classroom management and understanding of how students actively learned. Supporting factors such as training from the campus, experience in the field through the pamong teacher, and the use of actual references are very helpful in their capacity building. However, more reflective experience, mentoring, and intensive field practice are needed for them to be truly prepared to face the dynamics of the classroom independently and professionally.

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DISCUSSION

The results of the study show that the level of Pedagogical Content Knowledge (PCK) readiness of science teacher candidates in Indonesia and the Philippines is in the medium to high category. Prospective teachers in Indonesia show the same percentage of PCK readiness as their counterparts in the Philippines. Inferential analysis with the Independent Samples T-Test showed that there was no significant difference (P>0.05) in the aspects of Pedagogical Knowledge (PK) or Content Knowledge (CK). Prospective teachers in both countries have been able to implement pedagogical strategies. The results of qualitative interviews reinforce this interpretation. The main themes that emerged included: (1) the limitations of teaching practice experience in secondary schools that affected pedagogical readiness; (2) the influence of differences in the national curriculum on the structure and depth of science material; and (3) variations in teacher training approaches, especially in the use of technology and the integration of SDGs values. One of the participants from Indonesia emphasized the importance of "learning how to connect science content with environmental and sustainability issues." These findings clarify the contribution of the mixed methods approach. The readiness of the PCK between Indonesia and the Philippines can be explained by several contextual factors. Indonesia has implemented the Teacher Professional Education (PPG) program and the Merdeka Learning curriculum which provides space for prospective teachers to innovate in learning practices. These findings are in line with research by Nuangchalerm (2020) and Prachagool & Nuangchalerm (2019) which shows that PCK readiness in the ASEAN region is strongly influenced by national policies and local curriculum orientation. Research by Forsler et al. (2024) and Zubaidah et al. (2023) confirms that strengthening the collective PCK oriented towards Education for Sustainable Development (ESD) is important to improve the competence of 21st century teachers.

The results of this study are expected to expand the study of cross-country PCK in ASEAN through the lens of the SDGs, showing that the integration between CK, PK, and sustainability values must be adjusted to the social, cultural, and educational policy contexts of each country. The results of this study provide strategic input for universities and teacher education institutions (LPTK). First, teacher education programs need to balance strengthening PK and CK through the integration of cross-disciplinary project-based learning that is relevant to sustainability issues. Second, ASEAN cross-border training for prospective teachers is needed so that there is a good exchange of practices in the implementation of SDGs based PCK. Third, education policymakers

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in Indonesia and the Philippines need to strengthen partnerships between teacher training institutions to develop contextual and collaborative Education for Sustainable Development (ESD)-based curriculum. Thus, strengthening the PCK of prospective teachers not only improves teaching competence, but also forms educators who are able to become agents of change for sustainable development in the ASEAN region.Pedagogical Knowledge (PK) is the knowledge possessed by a teacher about effective learning principles, methods, and strategies. The indicators of Pedagogical Knowledge include several main aspects that include the ability to understand learning theories, design learning, manage classrooms, conduct assessments, and utilize educational technology. Teachers who have a good PK are able to understand how students learn, choose methods that suit their learning needs, and create a classroom environment that is conducive to learning. One of the main indicators is the understanding of prospective teachers about the student learning process. It includes knowledge of cognitive development theories, learning styles, motivations, and diverse learning needs. In addition, the ability to design learning is also an important indicator. Prospective teachers must be able to make a Learning Implementation Plan that is in accordance with the curriculum, choose relevant learning methods, and determine measurable learning goals.

Content knowledge (CK) includes an in-depth understanding of basic concepts in science, the ability to explain scientific phenomena, and the skill of integrating various branches of science such as physics, chemistry, biology, and earth science. CK is very important to ensure that prospective teachers are able to deliver material correctly, accurately, and relevantly. One of the main indicators of CK is mastery of basic concepts in science. Prospective teachers must understand the main principles in science, such as the laws of physics, chemical cycles, the structure and function of living things, and geological processes. This knowledge must be holistic, which means that prospective teachers are able to see the connections between branches of science to provide students with a complete picture of the world of science. Another indicator of a prospective teacher mastering content knowledge is that the teacher can explain and model scientific phenomena clearly and logically. Prospective science teachers must be able to use easy-to-understand language to explain abstract concepts to students. For example, explaining the concept of gravitational force or photosynthesis with concrete examples that are relevant to daily life. This ability also includes the use of visual aids or practicum to clarify explanations.

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The Content Knowledge (CK) aspect shows that 53.6% of prospective science teachers in the Philippines and 51.2% in Indonesia are in the "ready" category. This data shows that more than half of the respondents have adequate mastery of science material, almost half are still at a level of mastery that is not yet optimal. This condition explains why the readiness of CK which is in the "quite ready" category is still quite high. Mastery of content that has not been contextually integrated has direct implications for the weak formation of PCK, because prospective teachers tend to master concepts theoretically, but have not been able to transform them into meaningful and applicable learning. Therefore, strengthening CK not only needs to be focused on deepening science material, but also on the ability to relate material to real phenomena, environmental issues, and sustainable development challenges as a prerequisite for the formation of a strong PCK. The results showed that pedagogic readiness (PK) was relatively stronger than content readiness, especially in respondents from Indonesia. Most respondents have understood the basics of classroom management, learning strategies, and assessments. However, interview data revealed that this pedagogic skill is still procedural and not fully adaptive. Many respondents still rely on conventional learning models when facing class limitations, diversity of student characters, and student learning difficulties. This shows that pedagogic readiness is at the basic functional stage, but has not yet developed into flexible pedagogic decision-making as required in the PCK. The results of this study confirm that the main obstacle in improving PCK does not lie in the absence of PK or CK separately, but in the limited opportunity to practice the integration of both in the context of authentic learning. Teaching practices, learning reflection, and cross-disciplinary learning design are key factors that need to be strengthened in the education of prospective teachers. Without this experience, prospective teachers tend to view pedagogy and content as two separate domains.

The readiness of content knowledge can also be assessed from the ability of prospective teachers to relate science knowledge to the context of real life and global issues. For example, prospective teachers must be able to relate science concepts to environmental issues, such as climate change, pollution, or the energy crisis. This indicator shows that prospective teachers not only understand the theory, but also its relevance to student life and the challenges of the modern world. CK readiness indicators also include reflective abilities and knowledge updates. Science is a field that continues to develop, so prospective teachers must have a commitment to continue learning, keep up with the development of science, and update teaching materials according to

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new findings. Based on the above, the readiness of prospective science teachers is not only measured by the extent to which they master the material, but also from their ability to teach the material in a relevant, interesting, and contextual way.

Understanding pedagogy or PK is a requirement so that students can choose the right learning strategy to teach the material. Understanding of teaching materials or CK is also a basic requirement so that students are ready to teach various materials that will be given at school according to their level. If PK and CK have not been mastered, what happens is that prospective teachers will always focus on the content and learning materials only and lack pedagogical strategies so that learning becomes boring because there are few student learning activities. Pedagogical Content Knowledge (PCK) is a combination of mastery of material (content knowledge) and the ability to teach it (pedagogical knowledge) effectively. PCK indicators include the ability of prospective teachers to understand the concept of teaching materials in depth, know the best way to deliver the material to students, and recognize the learning challenges faced by students. PCK integrates knowledge about "what is taught" and "how to teach" to make learning more effective and meaningful. The readiness of Pedagogical Content Knowledge of prospective teachers can be reviewed from several main indicators. First, the ability to identify important concepts in teaching materials that are often misconceptions for students. Prospective teachers must understand learning difficulties that may arise and be able to design learning strategies that can overcome these difficulties. Second, the ability to choose learning methods that are in accordance with the material and student needs, for example using experiments, case studies, or project-based approaches for scientific materials such as science. In addition, the mastery of prospective teachers with learning aids, such as educational technology or interactive media, is also an important part of PCK readiness. Another indicator is the ability of prospective teachers to connect teaching materials with the context of students' daily lives. This aims to enable students to understand the relevance of the material they learn to the real world. The readiness of PCK can also be seen from the reflective ability of prospective teachers to evaluate the effectiveness of their teaching strategies and make improvements based on student input or learning outcomes. Thus, prospective teachers who have PCK readiness are able to teach material accurately, relevantly, and interestingly, while ensuring that students are actively involved in the learning process.

Content knowledge is now an uncertainty because information technology transfers big data excessively to everyone. Excessive material is sometimes not in accordance with the mental

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development of a student. Students have their own material packages that must be taught according to their age. This content knowledge should be the basic capital for students to be able to teach in schools. This content knowledge includes an understanding of the material, explaining what material will be taught at the beginning of the semester, and what material will be taught afterwards. If students are not ready to understand the material, then further learning will stop. For example, the material that will be taught in the initial class is basic material such as biodiversity and ecosystems, while the advanced material that must be taught is cells, reproductive systems, and genetics. The material should not be reversed from the way it is given to students because the material is a form of continuous learning. Content seems to be outdated and technology has changed.

The relationship between pedagogical knowledge and content knowledge can be explained in more detail through ten indicators of pedagogical competence. The explanation of the indicators of pedagogical knowledge (PK) and their relationship to content knowledge (CK) is presented as follows. First, teachers must understand students' psychological development and characteristics in order to determine appropriate learning strategies. Student characteristics directly influence the learning model applied; for example, active students are more suitable for discovery learning.

Second, mastery of learning theory enables teachers to guide students according to their learning styles so that the material can be easily understood. Pedagogical learning in the Philippines requires professional teachers to understand the importance of mastery of knowledge, content, and its relevance within and across the curriculum (Philippine DepEd Order No. 42, 2017). Teachers in Indonesia are also required to master competencies related to understanding learning theories. Learning theory serves as the foundation of the learning process because it shapes learning conditions. Therefore, learning theories facilitate teachers in selecting appropriate learning models and support students in learning effectively (Saefiana et al., 2020).

Third, the curriculum must be continuously developed in order to remain relevant to social changes, scientific advancement, and technological progress. Teachers are required to be able to translate the curriculum into effective and relevant learning activities. Curriculum development aims to adapt education to social changes as well as to explore previously unexplored knowledge (Harmita & Aly, 2023). Curriculum development must be carried out by teachers to update learning in accordance with technological developments and the demands of the times. Teachers in the Philippines, under the regulations of the Department of Education, are required to understand

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how to translate curricular content into relevant learning activities based on effective teaching principles. This requirement is also aligned with the expectations for teachers in Indonesia.

Fourth, the implementation of development activities is essential for improving teacher professionalism through innovation and the creative use of educational technology that utilizes the latest communication and information technology (Zahara et al., 2024). These activities include training in the development of learning media, workshops on assessment instruments, curriculum development workshops, learning model development workshops, and various learning support programs.

Fifth, technology-based learning media help convey instructional messages more effectively and improve student understanding. The use of technology includes LMS platforms, multimedia, social media, e-books, and online articles. Teachers can deliver learning materials optimally through learning media, enabling students to better understand the messages conveyed (Suminar, 2019). Online learning includes the use of platforms such as Google Classroom, Zoom, Microsoft Teams, and other Learning Management Systems.

Sixth, school facilities such as laboratories, computers, and internet access support the development of students' academic and non-academic potential. This development is carried out through practicum activities, intensive guidance, spiritual activities, and extracurricular programs. The development of students' self-potential can be supported through intensive mentoring, assistance for students who lack interest and motivation, role modeling, environmental awareness activities, daily spiritual enrichment, remedial programs, extracurricular activities, and the application of educational sanctions and guidance (Amaliyah & Rahmat, 2021).

Seventh, teachers must be friendly, open, honest, and able to communicate positively while providing space for student participation. The provision of appropriate rewards and the teacher's enthusiasm in teaching have been shown to increase students' motivation and learning comprehension. The teacher's ability to provide appropriate rewards for student success helps students better understand the material, while enthusiastic and sincere communication during learning activities enhances student motivation and comprehension (Putri, 2020).

Eighth, evaluation is conducted through three forms: diagnostic, formative, and summative evaluation to monitor students' learning progress (Idrus, 2019). Evaluation also serves as the basis for improving learning and determining students' promotion and graduation. The function of evaluation is to support the process, progress, and sustainable development of student learning

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outcomes, to identify students' strengths and weaknesses in specific subjects, and to provide information to parents or guardians regarding academic promotion and graduation (Idrus, 2019).

Ninth, reflection helps teachers critically examine their teaching practices to find solutions to classroom problems. Reflective teachers continuously improve the quality of learning as part of positive change. Through reflection, individuals become aware of their mistakes and strive to find solutions as concrete actions toward improvement (Manurung & Listiani, 2020). Teachers must also adapt their learning activities and identify appropriate strategies and technologies for delivering instructional materials effectively (Denby & Holman, 2002).

PCK is a framework that teachers need to have a deep understanding of the pedagogical components and structure of teaching materials. PCK is an important framework that must be known by a teacher, because PCK will always be used in learning activities and related to students' interest in learning and understanding the material (Tondeur et al., 2017). Koehler and Mishra (2019) argue that PCK helps teachers understand and can use this form of knowledge in the teaching and learning process. Teachers need to know what and how they apply learning strategies or models in a unique context in their classrooms.

The development of teachers' abilities towards PCK in ASEAN is influenced by national education policies which include government regulations and teacher competency activities in designing learning. The quality of learning will depend on learning activities, the way the material is delivered, and the way the teacher teaches. The challenge of this PCK can be seen from the suitability of learning strategies with teaching materials. A wise teacher must adapt the learning strategy to the characteristics of the material. However, for teachers who do not understand PCK, they will teach with the aim that the material is only delivered to students without looking at student activities in learning. Therefore, schools and organizers must have training courses or professional development programs for teachers and prospective teachers, especially professionals in the field of pedagogy and professionals in understanding teaching materials.

A good teacher is a teacher who is willing to develop learning strategies and adjust to the needs of students. Design thinking must be used for instruction-based classroom activities in preparing teachers in PCK. The state needs to set educational management goals by helping teachers know, understand and be able to use PCK in the teaching process (Blau, I. and Shamir-Inbal, 2017). Especially the teacher preparation program or pre-service teachers who are the younger generation in schools, who understand the development of new learning strategies and

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are enthusiastic about learning innovations in accordance with the demands of the 21st century. PCK's empirical studies of prospective science teachers show that all areas of knowledge show that they understand the integration of pedagogy, technology and bring different methods and ideas into the classroom learning environment. Teacher preparation programs need to pay attention to teacher competencies and embed PCK into the study program. While the nature of learners' learning is changing, teachers must adapt teaching strategies and they can utilize educational technology for effective teaching (Prachagool, V. and Nuangchalerm, 2019).

The Relationship of Pedagogical Content Knowledge (PCK) to Realize Sustainable Development Action

This research also makes a new contribution by linking PCK readiness with Education for Sustainable Development. The results of the study show that the integration of sustainability values in science learning can only be realized meaningfully if prospective teachers have the ability to integrate science concepts, pedagogic strategies, and the context of real problems simultaneously. Without a strong PCK, sustainability issues have the potential to become just memorization material, not a transformative learning experience. This is supported by the theory that, Pedagogical Content Knowledge (PCK) is an educational concept that emphasizes the ability of teachers to integrate content knowledge and pedagogy in a harmonious manner to create effective learning (Siow Heng Loke et al., 2015; Zubaidah et al., 2023)).

The results of this study provide important implications for educational institutions for education personnel in Indonesia and the Philippines. First, teacher education programs need to strengthen practice-based learning through the extension of teaching practice periods, reflective mentoring, and supervision that focuses on PCK integration. Second, cross-disciplinary science learning needs to be emphasized more so that prospective teachers are used to associating various science concepts in an integrated manner. Third, SDGs-based learning needs to be integrated not only as a material, but also as a pedagogic framework in the formulation of learning objectives, strategies, and assessments. This study confirms that the readiness of PCK for prospective science teachers in Indonesia and the Philippines shows good potential, but is not fully optimal. The medium to high readiness category indicates a strong foundation, but it also reveals gaps in the integration of pedagogy, content, and sustainability values. Strengthening this integration is the main prerequisite for the realization of science teachers who are able to foster critical thinking, environmental awareness, and sustainable real action in students in the ASEAN region.

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PCK has a central role in sustainable development action because it can help educators deliver educational materials related to sustainability in a way that is relevant, interesting, and meaningful for students. Teachers who have a strong PCK are able to bridge the gap between sustainability theory and real practice, so that students not only understand the concepts of sustainability, but are also motivated to take real actions in daily life. Based on the table 3, prospective students of Science teachers from the Philippines and Indonesia have a readiness that is very ready and quite ready more than 90%. This suggests that students who have PCK readiness have been considered able to bridge students to understand sustainability concepts and motivate them to take real action in their daily lives.

Education oriented towards sustainable development demands a multidisciplinary approach that combines social, environmental, and economic aspects (Araneo, 2024). Through PCK, teachers can design learning strategies that combine scientific knowledge, moral values, and practical skills. For example, in learning about climate change, a teacher with a good PCK can integrate scientific data on carbon emissions with discussions of environmental ethics and action-based projects, such as planting trees or reducing the use of plastics. Thus, PCK allows learning not only to be a means of knowledge transfer, but also a process of character formation that supports sustainable development.

PCK is also relevant in building students' critical awareness of global and local issues related to sustainable development. Teachers can use critical pedagogical approaches to help students understand the root causes of sustainability issues, such as social inequality, exploitation of natural resources, and pollution. Through this understanding, students are encouraged to think critically, find creative solutions, and take responsible collective action. PCK allows teachers to facilitate productive and collaborative dialogue in the classroom so that students feel they have an important role to play in sustainable development efforts (Forsler et al., 2024). In addition, PCK supports the development of 21st century skills, such as problem-solving, collaboration, and digital literacy, which are critical in realizing sustainable development (Shafie et al., 2019). In the learning process, teachers can utilize innovative technologies and methods to provide an authentic learning experience (Ramaila & Molwele, 2022). These innovative learning methods, for example, such as project-based learning and problem-based learning, can provide students with real learning experiences to provide meaningful learning. This approach not only increases student engagement,

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but also helps them understand the complexity of sustainability issues and the importance of cross-sectoral cooperation to address them.

The readiness of prospective science teachers in understanding Pedagogical Content Knowledge (PCK) plays an important role in supporting sustainable development actions. PCK includes not only the ability of prospective teachers to integrate knowledge of teaching materials and pedagogical strategies, but also their ability to convey scientific concepts relevant to sustainability issues, such as climate change, natural resource conservation, and environmentally friendly technologies. With a strong understanding of PCK, prospective teachers can design contextual, interdisciplinary, and meaningful learning, thereby equipping students with the awareness and skills to contribute to sustainable development. Therefore, improving the PCK competency of prospective science teachers must be a priority in teacher education to create a generation that is able to face global challenges and realize sustainable development goals.

CONCLUSION

This study shows that the readiness of PCK for science teacher candidates in Indonesia and the Philippines is still at a moderate level, with significant variation between countries. This research reflects that 44.9% of Indonesian students and 58.5% of Filipino students who will work as prospective science teachers have pedagogical readiness and content of science materials (PCK). As many as 41.5% of Indonesian students and 49.3% of Filipino students are in the category of being quite ready to know and master pedagogical skills and the content of science materials. The results of this study make a new contribution to the development of cross-border studies related to teacher readiness in the 21st century. The findings of this study have important implications for curriculum design, teacher training module development, and education policies that are in line with SDGs-oriented competencies. The results can serve as a basis for universities and teacher education institutions to strengthen the balance between content knowledge (CK) and pedagogical knowledge (PK).

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