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Technological, Pedagogical and Content Knowledge (TPACK) of Agriculture Teachers: Basis for Mentorship Program

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Abstract. *Education continuously undergoes transformation driven by evolving teaching-learning settings and paradigm shifts. The COVID-19 pandemic accelerated the adoption of various educational modalities, including online and flexible learning systems. Despite widespread use of technology in education, limited research has examined the technological, pedagogical, and content knowledge (TPACK) of agriculture teachers who face unique challenges due to specialized content and limited pedagogical training. This study addresses this gap by assessing the TPACK competencies of agriculture instructors at a College of Agriculture, where many lack formal teaching education. Using an adapted TPACK instrument, a descriptive quantitative design revealed that teachers perceived their Content Knowledge (CK) as fair, while perceiving moderate competence in Technology Knowledge (TK) and Technological Content Knowledge (TCK). These findings inform the design of a targeted mentorship program to support agriculture teachers in integrating technology effectively into their teaching. The study further revealed strong interrelationships among TPACK constructs, underscoring the integrated nature of technological, pedagogical, and content knowledge essential for effective technology integration in agriculture education.*

Keywords: *Technology, educational technology, agriculture, mentorship program, online education, TPACK*

1. Introduction

When the pandemic threatened most countries and disrupted essential activities, forcing academic institutions to close (Sutrisno et al., 2023) and resort to online classes. Teaching and learning have adopted a new platform, online education. As the Commission on Higher Education in the Philippines stated, the need to identify alternative learning modalities to accommodate the shift to online learning has become pressing. Likewise, based on CHED CMO No.4, s 2020, the implementation of flexible learning and teaching options, approaches, strategies, systems, pedagogies, and modalities in the higher education environment, may be adopted by all public and private HEIs in the country (Commission on Higher Education, 2020).

The integration of technology is evident as online education is growing rapidly and (Nash, 2015) stated there is little doubt that it will continue to expand until one day encompasses most higher education course offerings. Undeniably, the Internet and the

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World Wide Web have made significant changes to almost every aspect of our lives, from a global economy, and personal and professional networks to sources of information, news, and education (Nguyen, 2015). As online education rose, concerns also arose as to whether the quality of higher education has been put at stake because of the new avenue of academia (Nash, 2015). Further, the remarkable growth of online learning required keen attention to higher education framework.

Technology in education can help and improve student learning but effectively incorporating it into course instruction is a challenging task. The effectiveness of delivering a lesson with technology integration is captured by Technological Pedagogical Content Knowledge (TPACK), which refers to teachers' understanding of how technology, pedagogy, and content interact to enhance instruction (Santos & Castro, 2021). Built on Schulman's (1987) Pedagogical Content Knowledge (PCK), Koehler and Mishra (2008) introduced the TPACK framework, which expands PCK by including technological knowledge alongside pedagogy and content. The framework demonstrates the different knowledge domains each teacher should possess and the relationships among these knowledge bases (Fahadi et al., 2022).

Although the TPACK framework has been widely researched, most studies focus on general education subjects such as mathematics or science (Siloterio & Cajandig, 2025). TPACK refers to the integration of technology, pedagogy, and subject content knowledge by educators. However, empirical investigation of TPACK in agricultural education remains scarce, despite its critical importance due to the unique combination of specialized content and technology required in this field. Agricultural teachers face distinct challenges with limited access to area-specific technologies and often have less formal pedagogical training compared to their counterparts in other disciplines, leaving a significant gap in understanding their technological, pedagogical, and content knowledge integration.

This study contributes novel insights by applying the TPACK framework to agriculture teachers in the Philippines—a discipline and context underrepresented in TPACK research—thereby addressing a critical gap in discipline-specific applications of TPACK. Furthermore, it advances scholarship by linking TPACK findings directly to the design of mentorship programs, bridging the gap between understanding teachers' technological, pedagogical, and content knowledge needs and providing practical, context-sensitive strategies for professional development that support effective technology integration in agricultural education.

2. Literature Review/ Hypotheses Development

The TPACK framework is anchored on three main knowledge, content (CK), pedagogy (PK), and technology knowledge (TK) bases which yield, through interaction, equally important secondary knowledge bases of technological content (TCK), pedagogical content (PCK), and technological pedagogical (TPK) knowledge. CK refers to teachers' knowledge of the topic to be taught or studied (Koehler & Mishra, 2008) PK is the understanding of various instructional techniques and learning-enhancing practices (Fahadi et al., 2022). TK entails determining the best ways to integrate both current and new technologies in the classroom to enhance student learning and prepare them for a rapidly changing digital environment (Cherner & Smith, 2017).

PCK is domain-specific knowledge regarding teaching a certain topic (Kulgemeyer & Riese, 2018). Technology expertise complements pedagogical competence, allowing educators to include particular technology in lesson plans. (Fahadi et al., 2022) This is what encompasses TCK. TPK is the understanding of how teaching and learning might alter when certain technologies are employed in specific ways (Koehler & Mishra, 2008).

The TPACK framework is regarded as an indicator of effective teaching-learning (Zulkarnaen et al., 2023). For teachers to effectively use technology in the classroom, it is essential to evaluate and subsequently develop their TPACK (Schmidt et al., 2009)s Most academic institutions, including teachers, have not been fully prepared for the sudden shift to online education. According to a review by (Janssen et al., 2016), individuals look for support alongside their primary mentor–protégé relationship, based on early studies. Being exposed to various types of colleagues provides developmental support (Kram & Isabella, 1985). According to (Dobrow et al., 2012) developmental networks are networks comprised of developers such as coaches, mentors, and advisers from various social spheres that provide diverse amounts and types of support to career or psychosocial aspects. The amount of support delivered by a constellation of developers may also have positive effects on proteges' outcomes (Janssen et al., 2016).

The mentoring process may take place in several forms, varying from formal developmental interactions such as coaching sessions to long-term and intense relationships (Janssen et al., 2016). Mentoring entails modeling by the mentor and involves observation and imitation by the mentored or protégé. The Social Learning Theory by Albert Bandura holds that we learn from our interactions with others in a social context (Nabavi, 2012). Put simply people develop similar behaviors that they observe in others. When an individual has observed the behavior of other people, in this case, a mentor, especially if what they have observed are positive experiences or have involved rewards; the individual will assimilate and thus imitate that behavior. According to Bandura, imitation involves the actual reproduction of observed motor activities (Bandura, 1978). Bandura argued that individuals can learn new information and behaviors by watching or observing other people (Nabavi, 2012).

A theory of human motivation, Self-determination theory (SDT), is a theory that considers people as actively engaged, growth-oriented organisms who interact with their environment and strive towards intra- and interpersonal growth (Deci & Ryan, 2012). Central to SDT is the idea that humans have three basic needs: autonomy, competence, and relatedness (Janssen et al., 2016) and that fulfillment of these three is essential in an individual's growth and development (Deci & Ryan, 2012), which are integral in mentoring relationships.

Bandura's social learning theory, which posits that individuals develop new skills and behaviors through observation and imitation of role models, serves as a foundational framework for understanding the mentorship process examined in this study. In the context of agriculture teachers, observing mentors who effectively integrate technology can facilitate the acquisition of key TPACK competencies. This aligns with findings that practical, modeled experiences promote teacher confidence and skill in technology use. Therefore, applying social learning theory enables a deeper interpretation of how mentorship relationships can function as mechanisms for experiential learning and professional growth within agricultural education.

Similarly, Self-Determination Theory (SDT) highlights that autonomy, competence, and relatedness are fundamental psychological needs supporting motivation and development. Our study's findings reflect these principles, suggesting that mentoring interventions fostering these needs can enhance agriculture teachers' intrinsic motivation to engage with technology integration meaningfully. By linking SDT to TPACK development, the study provides a holistic understanding of how tailored mentorship can support not only skill acquisition but also the motivational drivers necessary for sustained teaching innovation.

In a study by Mu et al. (2018) that aimed to assess the effect of Professional Learning Communities (PLC) on teachers' Pedagogical

Content Knowledge (PCK), it was revealed that teachers' PCK benefitted from their participation in PLCs. Furthermore, the study found that within a supportive community, innovative teaching is likely to occur when teachers establish strong connections with colleagues. In a literature review by Waterman and He (2011), it was suggested that mentoring should be viewed and studied as a process rather than a program. Mentoring should be understood as a holistic process that is not limited to the involvement of assigned or chosen mentors but also includes unassigned colleagues, administrators, and even family members and friends.

Despite increasing emphasis on TPACK in education, agriculture teachers continue to face significant challenges in effectively integrating technology due to their specialized content knowledge and limited formal pedagogical training. These gaps in core TPACK domains hinder their ability to leverage technology fully in agricultural teaching contexts. Mentorship programs, specifically designed to address these unique challenges, can play a crucial role in enhancing agriculture teachers' technological, pedagogical, and content knowledge. Such targeted mentorship fosters digital literacy, improves technology self-efficacy, and supports practical application, ultimately promoting more effective technology integration in the classroom. This study, therefore, not only assesses the TPACK competencies of agriculture instructors but also seeks to inform the development of a mentorship program tailored to bridge these specific knowledge gaps, thereby advancing both educational practice and TPACK research within agricultural education. This study is grounded on the integration of three theoretical perspectives to provide a comprehensive understanding of agriculture teachers' competence in technology integration and the design of a mentorship program.

The Technological Pedagogical Content Knowledge (TPACK) framework (Koehler & Mishra, 2008) serves as the foundation, emphasizing the complex interaction of content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). Effective teaching with technology requires not only mastery of these individual domains but also their integration into secondary forms such as technological content knowledge (TCK), pedagogical content knowledge (PCK), and technological pedagogical knowledge (TPK). This dynamic interaction represents the core competencies necessary for agriculture teachers to successfully implement technology-enhanced instruction.

Building on TPACK, Bandura's social learning theory (1977) situates learning within social contexts, highlighting the importance of observational learning, imitation, and modeling. Mentorship offers a practical mechanism by which novice or less experienced agriculture teachers learn technological integration strategies by observing mentors who demonstrate effective practices. This social aspect reinforces skill acquisition and confidence in using technology.

Finally, Self-Determination Theory (Deci & Ryan, 1985) complements the framework by identifying key psychological needs—autonomy, competence, and relatedness—that enhance intrinsic motivation and engagement. Fulfilment of these needs through mentorship nurtures teachers' willingness to integrate technology and persist in professional growth.

Together, these frameworks form a conceptual lens through which this study assesses agriculture teachers' TPACK competence and examines how mentorship can be designed to address identified gaps. This integrated model directly informs the research questions focused on evaluating teachers perceived knowledge and formulating a targeted mentorship approach aimed at fostering technological pedagogical proficiency in agricultural education.

This study aimed to assess the teaching competence of agriculture teachers through their TPACK to provide recommendations as a basis for designing a mentorship program. This study is intended to determine the teachers' level in terms of core knowledge bases, specifically the PK, CK, TK, PCK, TPK, and TCK. Teachers' overall TPACK was also investigated.

Conceptual Framework

This study addresses the identified gap by focusing exclusively on agriculture instructors, assessing their perceived competence across core TPACK knowledge bases. In doing so, it provides novel insights into the current state of TPACK in agricultural education and identifies areas most in need of targeted professional development. These findings form the basis for a tailored mentorship program aimed at enhancing technology integration in agriculture teaching, thereby contributing to both the TPACK literature and agricultural education practice.

3. Methodology

The study adopted a descriptive design, specifically a quantitative approach. Utilizing standardized instruments, it assessed teachers perceived competence across the TPACK knowledge bases and their overall TPACK.

After appropriate permissions were sought and granted, and when the respondents had signified their voluntary participation, an initial survey was conducted online using a researcher-made questionnaire to determine the teaching background of the respondents and to further identify the study respondents. The respondents, who were resident and non-resident faculty members of a state university in Cebu, consisted of fourteen agriculture instructors of the College of Agriculture (COA). Sampling was purposive, selecting College of Agriculture teachers who fit the study criteria. Participants were identified as teachers who were not graduates of teacher education or technology-related programs and who had at least two semesters teaching prior to the COVID-19 pandemic, ensuring experience in face-to-face teaching. New teachers, those with professional education units, and those with substantial ICT training were excluded to focus on teachers needing assessment of TPACK competencies. This approach ensured the sample was relevant and representative of the target population given the study's objectives.

Table 1.
Demographic Profile of Respondents

Profile	Category	Number of teachers	Percentage (%)
gender	Male	6	54
	Female	5	46
Teacher Experience (Years)	1-2	3	27
	3	3	27
	4	2	18
	6	2	18
	8	1	9
Educational Attainment	Bachelor's degree graduate	2	18
	Master's degree with units	3	27
	Master's degree graduate	4	36
	Doctorate degree with units	2	18

Table 1 presents the teaching experience of the teacher respondents, in years. Teachers who have not taught for at least 1 year were excluded from studying. Of the 11 respondents, 3 teachers (27%) have been teaching for at least 1 to 2 years, while the remaining 8 teachers have been teaching for 3 years or more. Among the respondents, 2 teachers (18%) hold a bachelor's degree, while the majority, 4 teachers (36%), have earned a master's degree.

To assess teachers' TPACK, an adopted questionnaire developed by Sahin (2011) was utilized. The instrument is composed of a total of forty-seven (47) items categorized into seven (7) subscales corresponding to the dimensions of the TPACK. The instrument comprises the following subscales and the number of items per subscale: TK with 15 items, PK and CK each with six items, TPK, and TCK with four items, PCK with seven items, and TPACK with seven items. A five-point response set was used to represent respondents' perceptions including Complete=5, Quite=4, Moderate=3, Little=2, Not at all=1.

To determine the teachers' perceived TPACK competence, the weighted mean for each item of the 47-item instrument was determined. Similarly, the weighted mean for each TPACK knowledge base was determined.

This study involved minimal risk as it only required respondents to complete an anonymous questionnaire, and informed consent was obtained.

This study utilized descriptive statistical analysis to summarize respondents' perceptions of their Technological, Pedagogical, and Content Knowledge (TPACK) competencies. Weighted mean scores were computed for each item and knowledge base to assess perceived competence levels. Frequencies and percentages were used to describe respondent demographics and teaching experience.

To enhance the analytical depth of the study, descriptive statistics were complemented with measures of variability, including standard deviation (SD) and standard error (SE), calculated for each survey item to provide a comprehensive understanding of response distribution. Further, internal consistency reliability of the TPACK instrument was assessed using Cronbach's alpha, with coefficients ranging from .851 to .960 across subscales and an overall reliability of .963, indicating excellent instrument reliability. Additionally, Pearson correlation analysis was employed to examine the strength and direction of relationships among the TPACK knowledge domains, facilitating an exploration of their interrelatedness and enriching the interpretative framework of the study.

From the findings, implications were inferred especially based on the item's teachers perceived as low competence. A comparison between each TPACK knowledge base and the item per base was conducted by ranking the knowledge base and the items per base, respectively.

4. Findings and Discussion

Technology Knowledge

As defined by (Koehler & Mishra, 2008) TK covers everything from the blackboard to the whiteboard and is included in this information.

Table 2.
Teachers' Technology Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Solving a technical problem with the computer	2.64	*Moderate*	0.81	0.24
2	Knowing about basic computer hardware (ex., CD-ROM, motherboard, RAM) and their functions	2.73	*Moderate*	1.27	0.38
3	Knowing about basic computer software (ex., Windows, Media Player) and their functions	3.18	*Moderate*	0.98	0.30
4	Following recent computer technologies	2.91	*Moderate*	0.70	0.21
5	Using a word-processor program (ex., MS Word)	3.55	*Quite*	0.93	0.28
6	Using an electronic spreadsheet program (ex., MS Excel)	3.27	*Moderate*	1.10	0.33
7	Communicating through Internet tools (ex., e-mail, MSN Messenger)	3.82	*Quite*	1.08	0.33
8	Using a picture editing program (ex., Paint)	2.91	*Moderate*	0.94	0.28
9	Using a presentation program (ex., MS PowerPoint)	3.91	*Quite*	1.04	0.31
10	Saving data into a digital medium (ex., Flash Drive, CD)	3.55	*Quite*	1.13	0.34
11	Using area-specific software	2.55	*Little*	0.93	0.28
12	Using printer	3.82	*Quite*	0.98	0.30
13	Using projector	3.36	*Moderate*	1.36	0.41
14	Using scanner	3.55	*Quite*	1.21	0.37
15	Using digital camera	3.18	*Moderate*	1.17	0.35
	Grand Mean	**3.26**	***Moderate***	1.06	0.31

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

Table 2 presents the respondents' perception of their Technology Knowledge (TK). Of the 15 items in the TK base, 40% (6 out of 15) of the items were perceived by the teachers they were quite competent in. On the other hand, item 11 was revealed to be the item with the lowest meaning. Similarly, it is the item with the lowest meaning among all the items. In addition, it is the only item perceived to be "little" in terms of competence of the teachers. Moreover, teachers perceived that they were moderately competent in 53% of the TK items. Significant shifts driven by technology are changing agriculture requiring farmers and, especially agriculture teachers, to adapt (Kassim, 2020).

Of the items perceived by the teachers they were quite competent in, three items with the highest means include using a presentation program such as MS PowerPoint, using printer and communicating using internet tools such as e-mails and messenger. These items are reflective of technology practices that are considered an everyday or basic skill that teachers perform even before the shift to online or flexible modes of education. Thus, such could be attributed to the high perception of the teachers.

Item 11, the item with the lowest means, discusses the use of area-specific software. This includes programs and applications that are specific to Agriculture. This may include simulation software, genetic coding applications, and the like which are cutting-edge technology. These softwares are costly, implying that only a limited few can access such. This may explain why this item obtained the least teacher competence. (Weinert & Uslar, 2020) identified that area-specific software still has a significant work ahead before it is fully maximized. Even though agricultural innovation is advanced, technology adoption and use in digital agricultural practices are still in their early stages (Hansen et al., 2022). This indicates that additional work is required for this involved in education.

(Pambudi et al., 2023) highlighted that intention to use and ease of use positively influences users' acceptance of technology. (Mir & Padma, 2020) stated that beyond the technical perspective, technology acceptance is multifactorial, implying that other factors such as attitude and mindset of users, and availability of technology resource. A systematic review by (Thomas et al., 2023) identified that affective attitude towards technology was least emphasized. Thus, the findings may therefore be enhanced through mentorship.

Items that teachers perceived as moderately competent include items that discuss troubleshooting a technical problem with the computer, have knowledge of basic computer hardware (ex. RAM, motherboard) and their functions, and following recent computer technologies. These items obtained the lowest means in terms of the moderate level. Solving a problem with either hardware or software of the computer may be too technical wherein teachers seek assistance rather than learning and attempting to troubleshoot the problems themselves. Also, knowledge of basic computer parts may seem to be deficient, hence the majority of teachers nowadays utilize laptop computers rather than desktop computers. Further, teachers may fail to follow recent technologies as most are focused on their teaching loads and rely on training when there is a need to learn recent computer technologies.

Pedagogical Knowledge

Pedagogy knowledge (PK) refers to all methods and techniques that enable a teacher to deliver the content in the most effective manner (Kanuka, 2006). Table 3 depicts the perceived PK of the teacher respondents.

Table 3.
Teachers' Pedagogical Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Assessing student performance	3.55	*Quite*	0.93	0.28
2	Eliminating individual differences	3.36	*Moderate*	1.21	0.36
3	Using different evaluation methods and techniques	3.18	*Moderate*	0.87	0.26
4	Applying different learning theories and approaches (ex, Constructivist Learning, Multiple Intelligence Theory, Project-based Teaching)	2.82	*Moderate*	0.87	0.26
5	Being aware of possible student learning difficulties and misconceptions	3.36	*Moderate*	0.81	0.24
6	Managing class	3.64	*Quite*	0.81	0.24
	Grand Mean	**3.32**	***Moderate***	0.92	0.28

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

Assessing student performance and managing class obtained the highest means for this knowledge base. This is attributed to the fact that teachers regularly conduct updates through training and seminars to be adapted to changes in the curriculum which include the grading system and policies in dealing with students. Of the PK items that teachers perceived they were moderately competent in, the item that received the lowest mean is item 4 which includes using various learning theories and approaches such as Constructivist Learning, Multiple Intelligence Theory, and Project-based Teaching.

(Zarafshani et al., 2020) identifies that being an Agriculture teacher is challenging because they have to design learning opportunities where students can learn by doing as they apply concepts encompassing a broad and diverse skill set. This finding implies that while most Agriculture teachers learn certain pedagogical knowledge and skills, formal professional education training may be beneficial. The same is true for the next lowest item, the use of different evaluation methods and techniques. (Rivera-Ferre et al., 2021) concluded that, despite the barriers to utilizing specific pedagogical tools, it is still possible to advance agroecology with an emphasis on transformative education. Through mentorship, experiential sharing is shared.

Content Knowledge

Content Knowledge or (CK) answers the "What should be taught?" question (Margerum-Leys & Marx, 2002). According to (Shulman, 1987), it encompasses ideas and concepts, notions, theories, and law, and applying a certain knowledge specific to a certain discipline. Table 4 summarizes the CK of the teacher respondents.

Table 4.
Teachers' Content Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Knowing about key subjects in my area	4.18	*Quite*	0.87	0.26
2	Developing class activities and projects	3.91	*Quite*	0.94	0.28
3	Following recent developments and applications in my content area	3.64	*Quite*	0.81	0.24
4	Recognizing leaders in my content area	3.64	*Quite*	0.81	0.24
5	Following up-to-date resources (ex, books, journals) in my content area	3.55	*Quite*	0.93	0.28
6	Following conferences and activities in my content area	3.18	*Moderate*	0.75	0.23
	Grand Mean	**3.68**	***Quite***	0.85	0.26

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

In the CK base, teachers perceived their competence in 83% of the items to be quiet. This is notable as compared to the findings in the other knowledge bases. However, this is because all the respondents are BS Agriculture graduates and are licensed agriculturists. This explains the high meaning for this category. The observed higher Content Knowledge (CK) compared to Technology Knowledge (TK) and Technological Content Knowledge (TCK) aligns with established literature indicating that teachers generally have deeper expertise in their subject matter due to formal education and extensive disciplinary training (Shulman, 1986; Mishra & Koehler, 2006). Of the items, the highest perceived quite is the knowledge about key subject areas of the teacher respondents. It is empirical for teachers to acquire and assess new knowledge central to their field and regularly update their professional knowledge base (Jacob, F. et al., 2020). By participating in seminars and workshops, professionals in the Philippines must acquire Continuing professional development (CPD) units to renew their professional licenses as mandated (Tulo & Lee, 2022). This is why agriculture teachers have a high regard for their content base.

Remarkably, teachers perceived their competence to be moderate only in 1 item, following conference and activities in my content area. This finding is attributed to the circumstances that are out of the teachers' control such as limited knowledge and resources (financial, time, etc.) and opportunities for them to follow conferences and activities in their area of specialization. Though regarded as a tool for effective teaching (Popova et al., 2022), financial resources, along with others limit teachers' access to professional development.

Technological Pedagogical Knowledge (TPK)
TPK is the integration of technology with teaching. According to (Margerum-Leys & Marx, 2002). TPK necessitates a working knowledge of general pedagogical practices that are applied to the use of technology. Table 5 presents the TPK of the teachers.

Table 5.
Teachers' Technological Pedagogical Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Choosing technologies appropriate for my teaching/learning approaches and strategies	3.36	Moderate	0.67	0.20
2	Using computer applications supporting student learning	3.55	Quite	0.82	0.25
3	Being able to select technologies useful for my teaching career	3.27	Moderate	0.79	0.24
4	Evaluating appropriateness of a new technology for teaching and learning	3.27	Moderate	0.79	0.24
	Grand Mean	**3.36**	***Quite***	0.77	0.23

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

Of the four items in the knowledge base, only 1 TPK item was perceived by teachers they were quite competent in. This is the use of computer applications to support student learning. This is indicative that teachers employ ways that help students understand the lesson better. However, there is still a possibility to further strengthen this finding. On the other hand, two items found to have the lowest meaning for this knowledge base are being able to choose technologies useful for their teaching career and assessing the correctness of a new technology in their teaching-learning. Agriculture teachers need to be skilled with Technology (Zarafshani et al., 2020). This implies that although the teachers have a certain level of TPK, there is still a need to guide and assist them, especially in selecting the technologies that would best render their teaching effective. Modernization of agriculture is inevitable, requiring agriculture education to be at the forefront. It is thus essential for agriculture teachers to integrate technology and pedagogy (Nizametdinov Ali Akramovich, 2022).

Pedagogical Content Knowledge (PCK)
PCK refers to the teaching knowledge that is used in the delivery of a certain topic or content (Harris et al., 2009). It answers the question "How can this content be taught, effectively?" Table 6 depicts the PCK of the teachers.

Table 6.
Teachers' Pedagogical Content Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Selecting appropriate and effective teaching strategies for my content area	3.27	Moderate	0.79	0.24
2	Developing evaluation tests and surveys in my content area	3.36	Moderate	0.81	0.24
3	Preparing a lesson plan including class/school-wide activities	3.18	Moderate	0.75	0.23
4	Meeting objectives described in my lesson plan	3.36	Moderate	0.92	0.28
5	Making connections among related subjects in my content area	3.36	Moderate	0.92	0.28
6	Making connections between my content area and other related courses	3.27	Moderate	0.79	0.24
7	Supporting subjects in my content area with outside (out-of-school) activities	3.09	Moderate	0.70	0.21
	Grand Mean	**3.27**	***Moderate***	0.81	0.24

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

As depicted in Table 6, all of the items in the PCK dimension scored moderate. This implies that there is a need to strengthen the teachers' PCK considering that they do not have professional education units. One of the items with the lowest means is the item regarding preparing a lesson including class/school-wide activities. This is attributed to the fact that teachers in the College of Agriculture are pure sciences graduates. To modernize farming and assist farmers, agricultural education must be upgraded (Faskhutdinova et al., 2020).

The item with the lowest mean is the item stating teachers supporting subjects in their content area with extracurricular activities. (Sørensen et al., 2021) stated that the proactive impact of establishing networks and learning communities within the context of agriculture sustainability is both activistic and innovative, as the social relationships formed in these networks promote collective action. This finding emphasizes the need to increase linkages and partnerships as such provide opportunities for teachers to conduct out-of-school activities.

Technological Content Knowledge (TCK)

TCK, according to (Sahin, 2011), is a form of knowledge that demonstrates how technology and content interact and assist one another. Table 7 depicts TCK of the teacher respondents.

Table 7.
Teachers' Technological Content Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Using area-specific computer applications	3.09	Moderate	0.70	0.21
2	Using technologies helping to reach course objectives easily in my lesson plan	3.27	Moderate	0.90	0.27
3	Preparing a lesson plan requiring use of instructional technologies	3.27	Moderate	0.90	0.27
4	Developing class activities and projects involving use of instructional technologies	3.27	Moderate	1.01	0.30
	Grand Mean	**3.23**	***Moderate***	0.88	0.27

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

As shown in Table 7, all the items in the knowledge base were regarded by teachers as moderately competent. The item with the lowest means is the item concerning the use of area-specific computer applications. This is consistent with the results of the item in the TK knowledge base, and the only item in the entire result, to be little as perceived by the teachers. The use of area or content-specific computer applications requires further reinforcements for the teachers, and therefore the students. Considering that programs and software are not widely used since they are costly, there is a stronger need to enhance this aspect of teachers' TCK. (Soma, T., 2021) stated that an inclusive and equitable approach to digital agriculture is essential. Information and communication technology is a tool for knowledge sharing in education (Tiwari, 2022). (Vallera & Bodzin, 2020) looked into the impact of a technology-enhanced, project-based, STEM-integrated curriculum revealed that the participants' knowledge was increased. Likewise, they developed a more positive attitude implying that a technology-enhanced professional development intervention is beneficial. In general, based on the findings, there is a need to strengthen the teachers' TCK.

Technological, Pedagogical and Content Knowledge

TPACK is the overlap of the three knowledge bases which are at the very core of effective teaching (Harris et al., 2009) Additionally, it includes the successful integration of content and pedagogy with technology for effective teaching-learning. Table 8 presents the TPACK of the respondents.

Table 8.
Teachers' Technological, Pedagogical, and Content Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Integrating appropriate instructional methods and technologies into my content area	3.36	Moderate	0.81	0.24
2	Selecting contemporary strategies and technologies helping to teach my content effective	3.18	Moderate	0.75	0.23
3	Teaching successfully by combining my content, pedagogy, and technology knowledge	3.00	Moderate	0.77	0.23
4	Taking a leadership role among my colleagues in the integration of content, pedagogy, and technology knowledge	2.73	Moderate	0.90	0.27
5	Teaching a subject with different instructional strategies and computer applications	3.09	Moderate	1.06	0.31
	Grand Mean	3.07	Moderate	0.85	0.26

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

In the overall TPACK, all the items obtained a moderate response from the teachers. Although the findings are indicative of middle-ground competence, there is a need to further strengthen the TPACK of the respondents to facilitate quality education. In this knowledge base, the item with the lowest meaning is item 4: Taking a leadership role among my colleagues in the integration of content, pedagogy, and technology knowledge. This may imply that because the teachers are non-education or non-technology graduates, there is a strong need to introduce TPACK and how the interplay of the knowledge bases contributes to effective teaching.

TPACK Knowledge Bases

Table 9 presents the knowledge bases of TPACK. The knowledge bases are ranked in decreasing value.

Table 9.
TPACK Knowledge Bases

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE
1	Content Knowledge	3.68	Quite	0.85	0.26
2	Technological Pedagogical Knowledge	3.36	Moderate	0.77	0.23
3	Pedagogy Knowledge	3.32	Moderate	0.92	0.28
4	Pedagogical Content Knowledge	3.27	Moderate	0.81	0.24
5	Technology Knowledge	3.26	Moderate	1.06	0.31
6	Technology Content Knowledge	3.23	Moderate	0.88	0.27
	Grand Mean	**3.27**	***Moderate***	0.88	0.26

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

As shown in Table 9, of the TPACK knowledge bases, teachers perceived only 1 knowledge base they were quite competent in. This is attributed to the fact that all the respondents, the teachers at the College of Agriculture, are pure sciences graduates and are licensed agriculturists. In addition, a significant number have pursued graduate degrees. This explains why Content Knowledge (CK) is high.

Meanwhile, the knowledge bases that concern pedagogy are in the middle of the moderately perceived dimension. Because the respondents have been selected as those who have taught at least two semesters before the pandemic, the teachers have been accustomed to teaching. Likewise, they have received seminars and training concerning pedagogy.

TPACK Items Teachers Perceived Low Competence
As supported by Table 10 which shows the specific items with the lowest means, TK and TCK are the TPACK knowledge bases least moderately perceived by the agriculture teachers.

Table 10.
Teachers' Pedagogical Content Knowledge

Item No.	Item Statement	Mean	Verbal Interpretation	SD	SE	Knowledge Base
1	Using area-specific software	2.55	Little	0.93	0.28	TK
2	Solving a technical problem with the computer	2.64	Moderate	0.81	0.24	TK
3	Knowing about basic computer hardware (ex., CD-ROM, mother-board, RAM) and their functions	2.73	Moderate	1.27	0.38	TK
4	Applying different learning theories and approaches (ex, Constructivist Learning, Multiple Intelligence Theory, Project-based Teaching)	2.82	Moderate	0.87	0.26	PK
5	Following recent computer technologies	2.91	Moderate	0.70	0.21	TK
6	Using a picture editing program (ex., Paint)	2.91	Moderate	0.94	0.28	TK
7	Using area-specific computer applications	3.09	Moderate	0.70	0.21	TCK

Note. Verbal interpretation: 4.50–5.00 = Complete; 3.50–4.49 = Quite; 2.50–3.49 = Moderate; 1.50–2.49 = Little; 1.00–1.49 = Not at All. Grand SD and SE are the averages of the item standard deviations and errors, respectively, calculated from item-level statistics.

Some of the items presented in the table require technology knowledge which may be too technical for the agriculture instructors. These include knowing the basic parts of a computer's hardware as well as solving technical problems encountered. Technical problems have the possibility of delaying if not cancelling online classes. Likewise, being updated with the latest technologies is perceived to be the least moderate, which is attributed to the fact that technology is constantly fast-changing. Similarly, using a picture editing program is least moderately perceived because such program requires high-end computer units to operate. Further, Agriculture instructors may not feel the need to learn or use such programs. A study by (Murthy et al., 2022) revealed that agriculture teachers have a lack of technology knowledge among the other TPACK knowledge bases. For agriculture teachers, digital literacy, technology efficacy, and attitudes toward technology are crucial (Morey, T., 2020).

Notably, an item on pedagogy knowledge specifically, applying different learning theories and approaches (ex, Constructivist Learning, Multiple Intelligence Theory, Project-based Teaching) was found to be least moderately perceived by the respondents. This is consistent with the fact that Agriculture instructors are graduates of pure sciences and therefore require assistance and guidance in the exploration of educational principles, theories and concepts and its applications.

A study by (Ulfah et al., 2023) revealed that there is a relationship between emerging technology and students' interest in agriculture. Teachers are therefore an essential link. Teachers who took part in virtual mentoring programs demonstrated enhanced digital literacy and technological efficacy (Morey, T., 2020).

Teachers' adoption of technology does not happen overnight. In a study by (Hill, J. E., & Uribe-Florez, L., 2020), while teachers reported they were most competent in their pedagogical knowledge, they were least confident in their technological knowledge. (Tan et al., 2023) identified that most teachers with low TPACK is comprised with those that have low reported competence and confidence in using new pedagogies and are technology driven.

From a meta-analysis of 59 studies, (Ning et al., 2022) concluded that interventions significantly enhanced teachers' TPACK. From the study of (Ma et al., 2024), it was recommended that interventions and trainings may be applied to develop both holistic and subject-specific TPACK. Enhancing teachers' TPACK significantly develops their technology competence (Li et al., 2022). (Istiningsih, I., 2022) suggested that schools must provide more effective and professionally tailored technology support and training to enhance teacher competence, ultimately enhancing the quality of education. The findings suggest a need to further strengthen and enhance teachers' perception of their TPACK competence (Loseñara & Jugar, 2023) through interventions such as teacher training and mentorship to enhance agriculture teachers' technology competence and TPACK.

The results of this study are consistent with findings from other contexts, such as Murthy et al. (2022) and Hill & Uribe-Florez (2020), who reported that teachers generally demonstrate stronger content knowledge compared to technological knowledge, particularly in specialized fields like agriculture. These studies similarly emphasize the need for targeted professional development focusing on both technological skills and their pedagogical application within specific content areas to enhance effective technology integration in teaching.

Based on the findings, agriculture teachers face distinct challenges in integrating technology compared to other disciplines due to limited access to specialized technological resources and equipment suited for agricultural content, high costs, and often inadequate technical support. Additionally, aligning technology use with the hands-on, practical nature of agricultural teaching requires tailored professional development, making effective technology integration more complex in this field

Instrument Reliability

Prior to analyzing the TPACK knowledge bases, Cronbach's alpha reliability coefficients were calculated to assess the internal consistency of the questionnaire. Table 11 presents the reliability coefficients for each knowledge base and the overall TPACK instrument. All subscales demonstrated good to excellent internal consistency, with Cronbach's α values ranging from .851 to .960. The overall TPACK instrument achieved a Cronbach's α of .963, indicating excellent reliability and confirming that the items consistently measured the intended constructs.

Table 11.
Cronbach's Alpha Reliability Coefficients for TPACK Knowledge Bases

Knowledge Base	Number of Items	Cronbach's α	Interpretation
Technology Knowledge (TK)	15	.872	Good
Pedagogy Knowledge (PK)	6	.851	Good
Content Knowledge (CK)	6	.900	Excellent
Technological Pedagogical Knowledge (TPK)	4	.906	Excellent
Pedagogical Content Knowledge (PCK)	7	.934	Excellent
Technological Content Knowledge (TCK)	4	.960	Excellent
Technological Pedagogical Content Knowledge (TPACK)	5	.915	Excellent
Overall TPACK Instrument	47	.963	Excellent

Note. Cronbach's α values indicate internal consistency reliability of each knowledge base. Interpretation criteria: α ≥ .90 = Excellent; .80 ≤ α < .90 = Good; .70 ≤ α < .80 = Acceptable; .60 ≤ α < .70 = Questionable; α < .60 = Poor. n = 11.

Interrelationships and Implications of Knowledge Domains in the TPACK Framework

The study found strong correlations among components of the TPACK framework, as shown in Table 12, emphasizing the integrated nature of teachers' knowledge in technology, pedagogy, and content. Pedagogical Knowledge (PK) closely relates to Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Pedagogical Content Knowledge (PCK), and Technological Content Knowledge (TCK), highlighting the synergy between teaching strategies and content mastery when enhanced by technology. Similarly, CK correlates strongly with PK, PCK, TPK, and TCK, reinforcing that subject expertise aligns with effective teaching methods and technology use.

Table 12.
Pearson Correlation Matrix: TPACK Knowledge Base

Variable	TK	PK	CK	TPK	PCK	TCK	TPACK
TK	-	0.494	0.564	0.388	0.515	0.394	0.489
PK	0.494	-	0.945**	0.895**	0.929**	0.858**	0.665*
CK	0.564	0.945**	-	0.839**	0.900**	0.806**	0.660&
TPK	0.388	0.895**	0.839**	-	0.879**	0.774**	0.602
PCK	0.515	0.929**	0.900**	0.879**	-	0.829**	0.764**
TCK	.394	0.858**	0.806**	0.774**	0.829**	-	0.783**
TPACK	.489	0.665*	0.660*	0.602	0.764**	0.783**	-

Note. Correlation strength: |r| ≥ .90 = very strong; .70 ≤ |r| < .90 = strong; .50 ≤ |r| < .70 = moderate; .30 ≤ |r| < .50 = weak; |r| < .30 = very weak. Significance levels: p < .01 (two-tailed); p < .05 (two-tailed); no asterisk indicates not significant.

Technological knowledge domains—TPK, TCK, and TPACK—also exhibit strong interrelationships, with Technological Content Knowledge (TCK) being the strongest predictor of overall TPACK. This suggests that teachers proficient in integrating technology with content demonstrate higher overall competence in technology-supported instruction. These findings underscore the importance of cultivating interconnected skills across content, pedagogy, and technology for effective teaching in digital learning environments, supporting the premise that TPACK is a unified construct rather than separate knowledge components. Future research could explore how these interrelations translate to classroom outcomes.

5. Conclusion

As education continually evolves to keep pace with changing times, teachers must adapt to innovations such as the growing role of technology in teaching and learning. Amplified by the pandemic, technology has become indispensable as schools adopted online and flexible education modes. This study found that agriculture teachers perceive their content knowledge as strong, yet integrating technology with content remains their least developed knowledge base.

Technology Knowledge and Technological Content Knowledge were among the lowest perceived competencies, highlighting areas for targeted improvement. The instrument demonstrated excellent internal consistency, supporting the validity of interpreting the complex interplay among technological, pedagogical, and content knowledge within this agricultural education context. These findings contribute theoretically by reinforcing TPACK's comprehensive framework in agriculture education, practically by underscoring the need for professional development and mentorship programs that concurrently develop all TPACK domains, and policy-wise by urging bodies like CHED to prioritize support for agricultural educators' technology integration skills in evolving instructional modalities.

Recommendations and Implications for Future Research

The results of this study suggest several important implications:

(1) For practice: Professional development programs, particularly mentorship, should focus on introducing agriculture teachers to content-specific software and applications, such as simulations and genetic coding tools, to provide effective technology alternatives in lieu of traditional in-class activities. Additionally, pedagogy mentorships emphasizing teaching-learning principles and integrating technology, along with training in basic ICT troubleshooting, are essential to support teachers in flexible and online education.

(2) For policy: Educational policymakers and institutions like CHED should prioritize funding and designing targeted mentorship and training programs to build agriculture teachers' capacity for effective technology integration. Policies should also support access to affordable agricultural technology applications and innovation in teaching resources to overcome financial and technical barriers.

(3) For future research: Studies can explore the efficacy of specific mentorship models and technology tools in enhancing TPACK integration in agricultural education and investigate longitudinal impacts on teacher performance and student learning outcomes.

Limitations of the Study

The study's respondents include all faculty members from the College of Agriculture at one campus. Future research could expand to include agriculture faculty from additional colleges and universities, as well as high schools offering agriculture courses, to gain a broader understanding of agriculture teachers' TPACK. Recommendations for designing a mentorship program are based solely on this study's findings, and incorporating additional data sources could be beneficial.

Declarations

Author contribution

All authors contributed equally to this paper and are listed as co-primary contributors. All authors read and approved the final paper.

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Competing interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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