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Bridging Theory and Practice in Stem Teacher Education: A Quantitative Study of Pre-Service Teachers' Pedagogical Knowledge and Classroom Enactment

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Abstract

STEM education has become a strategic priority in teacher preparation programmes. However, there is a persistent gap between pedagogical knowledge acquired during coursework and its effective implementation in classroom practice. This study explores the level of STEM pedagogical knowledge among pre-service teachers and examines whether demographic factors such as gender and academic major influence their pedagogical competencies. A cross-sectional survey was designed and employed on 114 pre-service teachers who has enrolled in science, mathematics, and elective programmes at an Institute of Teacher Education in Malaysia. Data was collected using a questionnaire, validated 25-item Likert-scale measuring five dimensions of STEM pedagogical knowledge: STEM Integration Knowledge, STEM Pedagogical Strategies, STEM Lesson Design Knowledge, Technology Integration Knowledge, and STEM Assessment Knowledge. The instrument demonstrated excellent internal consistency (Cronbach's $\alpha = 0.971$). Data were analyzed using SPSS Version 26 through descriptive statistics, independent samples t-tests, one-way ANOVA, and Pearson correlation analysis. The findings indicate that respondents demonstrated a high level of STEM pedagogical knowledge ($M = 4.12$, $SD = 0.59$). No statistically significant differences were found across gender or academic major ($p > .05$). Pearson correlation analysis revealed strong positive relationships among all constructs ($r = .683–.808$, $p < .001$), indicating that the dimensions of STEM pedagogical knowledge are closely interconnected. These results emphasize the value of thorough pedagogical preparation in teacher education programs to improve future educators' integrated STEM teaching competencies.

Keywords: - STEM pedagogical knowledge, pre-service teachers, teacher confidence, quantitative study

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1. Introduction

The idea of STEM education science, technology, engineering, and mathematics is increasingly acknowledged as a crucial component of national development, innovative capacity, and student readiness for the challenges of a challenging and technologically advanced future. STEM is an integrative approach that encourages flexibility, critical thinking, creativity, and problem-solving as opposed to a set of specialties. The given approach is also evident in the national educational strategy of Malaysia, as the Ministry of Education has identified the significance of teachers in promoting inquiry-based, learner-centered, and problem-based learning conditions, along with supporting STEM learning (KPM, 2020a).

The quality of teacher preparation, especially the degree to which pre-service teachers acquire pedagogical competence in accordance with contemporary STEM practices, is crucial to achieving these policy goals. Pre-service teachers in teacher education are expected to develop sound pedagogical frameworks and apply theoretical knowledge to effective classroom instruction.

However, it is widely recognized that it is not an easy task to develop the ability of teaching. The process of teaching requires way beyond the alone subject-matter wisdom, it further requires the ability to transform the knowledge of a discipline into learning experiences, methods and thoughts that can be cognitively reachable to the learner. Such transformation is underscored by the notion of pedagogical knowledge by Shulman that highlights the idea of effective teaching being the culmination of knowing the content and knowing how that content can be taught and learned (Shulman, 1986). Studies also indicate discrepancies between theory and practice although courses are organized, microteaching and practicum experiences (Darling-Hammond, 2006). This theory-practice gap has been the subject of concern in literature on teacher education.

Pre-service teachers in universities often demonstrate the understanding of learner-centered pedagogies, inquiry-based tactics, and problem-solving techniques; however, they have difficulties applying the practices into practice in the actual educational contexts. Empirical studies found out that the transition between pedagogical knowledge acquisition and pedagogical enactment depends on a variety of factors, namely, the needs of classroom management, institutional constraints, expectations of mentors, pressure in the field of assessment, and the absence of instructional resources (Hudson, 2013 & OECD, 2024). These challenges are most evident among pre-service teachers during practicum experiences where pre-service teachers need to reconcile pedagogical objectives with the realities of classroom instruction.

Malaysia has national efforts to increase its competitiveness in economics, technological creation, and labor readiness, among which STEM education is one of them (KPM, 2020b). Thus, teacher training centers, particularly the Institut Pendidikan Guru Malaysia (IPGM) will play a vital role in providing future educators with the pedagogical competency needed to facilitate these national interests. To encourage the development of pedagogical reasoning and reflective practice, pre-service teachers participate in organized programs which include pedagogical theory, disciplinary knowledge, assessment literacy, classroom management, and creative teaching practices.

Nevertheless, recent studies reveal that possession of pedagogical knowledge is not a sure or effective way to implement the knowledge in the classroom. Teachers at Institut Pendidikan Guru Kampus Sultan Abdul Halim (IPGKSAH) are pre-service teachers who are trained to engage in learning opportunities such as microteaching and school-based practicums with objectives of facilitating theory-practice interface. The pedagogical performance witnessed in these environments is highly diverse. Some pre-service teachers demonstrate self-confidence, creativity, and adaptable instructional practices, whereas other teachers complain about the inability to keep students engaged, manage classroom dynamics, and implement inquiry-based STEM in exam-centered classrooms.

This variety brings the need to gain more insight into the variables that affect the transformation of pedagogical knowledge into instructional practice. Another useful paradigm through which these dynamics can be conceptualized is the concept of reflective practice by Schon, according to which the development of professional competence can be understood through the existence of successive reflective-in-action and reflective-on-action cycles (Schon, 1983). Practicum opportunities to introspect, mentor, and criticize may significantly influence the way pre-service teachers learn about the challenges and enhance their pedagogical decisions. When teacher preparation and school expectations align, pre-service teachers can have the benefit of making easier transitions into the classroom practice, and vice versa, when they are averted to uncertainty, diminished confidence, and reliance on more traditional teaching forms (Hudson, 2013).

Not much quantitative information exists to examine the pedagogical knowledge of pre-service teachers, their challenges, and the resources that facilitate classroom implementation in the Malaysian teacher education setting, though there are long conceptual debates about the theory-practice gap. A significant part of the existing literature concentrates either on small-scale case studies or on qualitative results. Even then as significant as these contributions are, the fact that teacher education institutions do not have more extensive empirical measurement undermines their ability to discern trends, detect needs, and develop specific pedagogical interventions. To bridge this gap, the present research is expected to generate quantitative information on three interrelated dimensions, such as the level of STEM pedagogical knowledge, perceived challenges on the way to classroom application of such knowledge, and the teaching resources that pre-service teachers perceive as contributing to successful classroom implementation. The research is aimed at offering contextually specific information that can be used to improve the curriculum, design practicum and mentoring activities because the research will position these variables within the context of IPGKSAH. To ensure the continuation of the bigger STEM education agenda within Malaysia whereby teacher competence remains a very critical component in influencing student engagements and quality of education, this research is very essential to enhance teacher training.

2. Literature Review

Pedagogical Content Knowledge (PCK) is a basic model of teacher competency that has been developed in STEM education and whose original notion was developed by Shulman (1986) and was elaborated in the multidimensional model proposed by Magnusson et al. (1999). In this perspective, good teaching involves the ability to anticipate challenges faced by the learners, to convert disciplinary knowledge into forms that have pedagogical significance, as well as to align teaching and assessment with assessment objectives that involve epistemic learning.

PCK is a contextual and discipline-specific phenomenon which grows out of the experience of education, reflective practice, and interaction with the context. It is neither an agreed body of information nor an inevitable by-product of mastery of the content, as modern scholarship keeps pointing out. Lack of uniformity in pedagogical ability is a common finding of empirical research on pre-service STEM teacher development. Pedagogical transformation, particularly the development of cohesive instructional representations, anticipating misconceptions, and integrating evaluation methods that measure conceptual insights, has been found to be a problem experienced by pre-service teachers, despite their often demonstrating a satisfactory approach to declarative pedagogical knowledge or content knowledge (Opus et al., 2025 & Cahyani, 2025).

These findings indicate that knowledge is not necessarily classroom-ready competence, which confirms the fear of variability in the enactment of pedagogy. Such findings are further corroborated by the fact that the levels of STEM pedagogical knowledge of pre-service teachers and their perceived readiness to use it in their instruction are important aspects to be evaluated. Nevertheless, the literature also has more positives. Some studies indicate that certain pedagogical interventions such as the inquiry-based learning, STEM-integrative, and lesson study can enhance the PCK dimensions of pre-service teachers (Berisha & Vula, 2021). These findings suggest that in case the learning processes are arranged in a collaborative and coherent way with the educational goals, the pedagogical growth could occur.

Nevertheless, research also cautions that such treatments rely on curriculum coherence and continuous reflective practice in order to be successful. Pedagogical competence can be improved with disproportion or temporarily when new pedagogies are instated without correspondence to assessment procedures or realities. The contrasting outcomes highlight the importance of considering the two levels of pedagogical knowledge and the situational challenges that inhibit the enactment of pedagogical knowledge. There is more complexity as studies examining the influence of previous professional experience and disciplinary knowledge indicate.

An essential requirement of good teaching is a strong knowledge of discipline, which can be supported by research on career-change teachers and individuals with engineering background (Love & Hughes, 2022 & Yip, 2025). Such individuals will be challenged by facilitating learning, classroom control, and adaptive learning despite often possessing excellent mastery of material. These findings reinforce a notion that, pedagogical knowledge should be intentionally constructed in the teacher training programs, and defy traditional ideas that pedagogical competence is guaranteed only by disciplinary expertise. These predicaments are better illuminated in the literature on the theory-practice divide. Studies indicate that, pre-service teachers are unable to practice their pedagogical skills because they have cognitive, psychological and environment constraints in conjunction with knowledge gaps. Cognitive overload, lack of instructional confidence, ineffective classroom immersion, and unreliable mentor modelling hinder the process of converting theoretical knowledge into a contextual practice (Anand & Gangmei, 2023 & Resch et al., 2022).

Additionally, the pre-service teachers who are exposed to the reform-based pedagogies can still fall back to the familiar teacher-centred practices as a result of the already formed attitudes shaped in their past education. These findings demonstrate the importance of researching the perceived challenges in the utilization of STEM pedagogical information. Conversely, some studies focus on highlighting the role of microteaching, structured practicum learning opportunities, and rehearsal-driven pedagogies in enhancing pedagogical confidence and short-term instructional preparation (Crichton et al., 2021).

Even though such approaches can lead to greater perceived competence, the researchers caution that in the absence of ongoing mentoring, iterative feedback, and well-established school-university partnerships, they can be difficult to sustain (Mutende, 2025 & Resch et al., 2022). These conflicting outcomes demonstrate that pedagogical preparation methodologies may produce a range of outcomes, based on the level of structural continuity and alignment of the context in which the teacher education programs occur. Consequently, the research of the resources facilitating pedagogic enactment remains an important discipline. Systemic alignment is also important as revealed in comparative studies carried out in different educational settings. In most of the developed education systems, teacher preparation programs emphasize the use of mentored practicum experiences, collaborative professional learning, and reflective practice (La Velle, 2019). Yet, the implementation of the instructional expertise requires congruence between coursework, mentorship, and classroom realities and is required to succeed particularly when the situation is characterized by abundant resources (Yip, 2025).

In developing countries, institutional constraints can also widen the theory-practice gap, including the unformalized nature of mentoring systems, insufficient practicum experiences, and unavailable instructional resources (Opus et al., 2025 & Mutende, 2025). It has been demonstrated that the degree of congruence between teacher teaching preparation and classroom expectation plays a significant part in teacher education program performance despite the contextual differences. In models that seek to establish a connection between theory and practice, reflective practice has been noted as one of the central mediation mechanisms in the development of pedagogies. Nonetheless, recent literature warns that reflection is best done when it is well organized. Unstructured or superficial reflection may also yield minimal pedagogical change, and reflective practices that are incorporated into collaborative planning, lesson-study, and mentored feedback have the potential to encourage more in-depth, reasoned pedagogical thinking and growth in PCK (Roberts et al., 2021 & Næsheim-Bjørkvik & Larssen, 2019).

Moreover, it has been demonstrated that communities of practice and organized mentoring communities can enhance the bond between pedagogical theory and classroom performance (Yip, 2025). Such results underscore the need to investigate the aspects of support that allow pre-service teachers to suitably apply the knowledge of pedagogy. The current scholarship is still rich, but there are still a number of gaps in the study. Most of the studies on STEM PCK focus on conceptualization and measurement, and very little effort is made on how pre-service teachers control the process of applying pedagogical knowledge in the classroom (Aydin-Gunbatar et al., 2020 & Cahyani, 2025). Besides, research focused on disciplines often provides fragmented results that are not well integrated into larger-scale cross-STEM explanatory models (Love and Hughes, 2022 & Opus et al., 2025).

Although the empirically validated models of the pedagogically coherent integration lack, the emerging studies on digital and AI-enhanced STEM education also promise a lot (Wulff et al., 2025). All these negatives indicate that there is need to have empirical studies which consider the levels of pedagogical knowledge and the barriers and resources influencing classroom practice under some teacher education circumstances. Even despite the richness of existing literature, there are still several gaps in studies.

Most of the studies regarding STEM PCK focus on conceptualisation and measurement with minimal attention on how pre-service teachers can deal with the process of pedagogical knowledge to classroom practice (Aydin-Gunbatar et al., 2020; M & Cahyani, 2025). Also, the research that is grounded in particular disciplines often produces fragmented information that cannot be effectively integrated into more generalized cross-STEM explanatory models (Love and Hughes, 2022 & Opus et al., 2025). Although empirically validated models of the pedagogical coherent integration are lacking, other new studies about digital and AI-enriched STEM education are also promising (Wulff et al., 2025). All these limitations lead to need of empirical researches that examine pedagogical knowledge level besides the challenges and resources that influence classroom implementation within specific teacher education settings.

3. Methodology

The design of this study was a quantitative survey study that aimed at analyzing the concept of converting STEM pedagogical knowledge into classroom practice by pre-service teachers. The survey technique allowed measuring pedagogical knowledge systematically, its use, perceived difficulty and empowering the way through a large respondent sample. There was also the possibility of making comparisons between specialization groups (science major, mathematics major, and elective) based on the design, which helped to analyze the disciplinary differences in pedagogical implementation.

The sample population was 114 pre-service teachers studying in Institut Pendidikan Guru Kampus Sultan Abdul Halim (IPGKSAH). The respondents were recruited based on various PISMP cohorts of STEM-related programmes. The individuals were pedagogical coursework, microteaching, and practicum participants and therefore were apt to be used in exploring the theory-practice relation in STEM pedagogy.

The sampling method used was purposive sampling whereby the respondents have firsthand experience of STEM pedagogy and classroom practice. 114 eligible students were taken on board according to the practicum and the specialization. They were collected in IPGKSAH during tutorials, lecture time, and on the internet by using Google Forms to make them accessible and have high response rates. A structured questionnaire was used in the collection of data on four constructs, which included Pedagogical Knowledge, (2) Application in Classroom Practice, (3) Challenges/Barriers and (4) Pathways/Supports.

Products were created using pedagogical content knowledge theory and the current STEM education books. The respondents had their levels of agreement gathered using a five-point Likert scale. The validation was also done by expert review, which incorporated the face and content validity process. The relevance, clarity and theoretical alignment of items were maintained by use of a Content Validity Index (CVI) process. Cronbachs alpha was used to determine reliability and all constructs portrayed good to excellent internal consistency (a =0.881-0.914) which is higher than the recommended value of 0.70. Table 1 presents the outcomes of the reliability test based on Cronbach alpha of the constructs of STEM pedagogical knowledge.

Table 1: Reliability analysis of STEM pedagogical knowledge constructs (Cronbach's alpha)

Code	Construct	No. of items	Cronbach's Alpha
SPK1	STEM Integration Knowledge	5	0.889
SPK2	STEM Pedagogical Strategies	5	0.911
SPK3	STEM Lesson Design	5	0.890
SPK4	Technology Integration	5	0.881
SPK5	STEM Assessment Knowledge	5	0.914

Prior to data collection, institutional permission was sought. The pilot test aimed at perfecting the clarity and flow of responses. The questionnaire was completed and sent out online in the form of a Google Form. The participants were briefed about the purpose of the study, the voluntary nature of the study, and confidentiality of the study. The answers were safely kept and ready to be analyzed.

The analysis of data was done in SPSS Version 26. The levels of STEM pedagogical knowledge, challenges, and supports were identified with the help of descriptive statistics (mean, standard deviation, and frequency). The independent samples t-tests were used to investigate gender differences, one-way ANOVA to compare pedagogical knowledge among the respondents in terms of their major (science, mathematics and elective) and Pearson correlation analysis to investigate the relationship among constructs of STEM pedagogical knowledge. There were strict ethical standards followed. The involvement was voluntary and informed consent was taken and confidentiality assured. Anonymization and safe storage of data ensured privacy of respondents.

4. Results

The section presents the findings of the statistical tests that are performed to answer the research objectives of the study. Pre-service teachers were evaluated on the level of STEM pedagogical knowledge on five dimensions initially by descriptive statistics. Subsequently, one-way ANOVA and independent samples t-tests were conducted to determine whether there were any significant differences based on academic major and gender. Finally, the Pearson correlation analysis was performed to identify the correlations between the constructs of STEM pedagogical knowledge.

4.1 Level of STEM Pedagogical Knowledge by Constructs

Based on Table 2, the descriptive analysis has shown that pre-service teachers were highly knowledgeable in STEM, pedagogically, in all constructs. The average scores were between 4.03 and 4.19 using a five-point Likert scale. Technology Integration Knowledge (M = 4.19, SD = 0.56) followed by STEM Pedagogical Strategies (M = 4.15, SD = 0.59) and STEM Integration Knowledge (M = 4.13, SD = 0.63) had the highest mean scores. The mean total score of the instrument used was 4.12 (SD = 0.59), which means that most respondents felt that they mostly possessed a great deal of knowledge of STEM pedagogy.

Table 2: Mean and standard deviation of STEM pedagogical knowledge constructs

Construct	Items	Mean	SD
SPK1: STEM Integration Knowledge	1–5	4.13	0.63
SPK2: STEM Pedagogical Strategies	6–10	4.15	0.59
SPK3: STEM Lesson Design Knowledge	11–15	4.11	0.60
SPK4: Technology Integration Knowledge	16–20	4.19	0.56
SPK5: STEM Assessment Knowledge	21–25	4.03	0.59
Overall Instrument	**1–25**	**4.12**	**0.59**

Level of indicator: 1 Mean Level 1.00-2.33 =low, 2.34-3.66= Moderate and 3.67-5.00 high

4.2 Comparison of STEM Pedagogical Knowledge by Gender

Independent samples t-test was to be used to find out whether STEM pedagogical knowledge showed gender differences among pre-service teachers. Based on Table 3, the data showed that there were no statistically significant differences between male and female respondents in all the five constructs: STEM Integration Knowledge (t = 0.69, p = .497), STEM Pedagogical Strategies (t = 0.09, p =.929), STEM Lesson Design Knowledge (t = 0.73, p =.472), Technology Integration Knowledge (t =0.92, p =.308), and STEM Assessment Knowledge. These results show that gender is not a major factor that can affect STEM pedagogical knowledge among the interviewees.

Table 3: Comparison of STEM pedagogical knowledge by gender

Construct	Male Mean	Female Mean	t	p-value	Interpretation
SPK1: STEM Integration Knowledge	4.05	4.15	-0.69	0.497	Not significant
SPK2: STEM Pedagogical Strategies	4.16	4.15	0.09	0.929	Not significant
SPK3: STEM Lesson Design Knowledge	4.03	4.13	-0.73	0.472	Not significant
SPK4: Technology Integration Knowledge	4.10	4.22	-0.92	0.361	Not significant
SPK5: STEM Assessment Knowledge	3.91	4.06	-1.03	0.308	Not significant

With mean scores ranging from 4.03 to 4.19, the results show that pre-service teachers exhibit a high level of STEM pedagogical knowledge across all dimensions. The instrument's outstanding internal consistency (α = 0.971) was confirmed by the reliability analysis. There were no statistically significant differences between male and female respondents in any of the five constructs, according to independent samples t-test results (p >.05).

4.3 Differences in STEM Pedagogical Knowledge by Respondents' Major (Science, Mathematics, and Elective)

A one-way ANOVA was conducted to examine whether STEM pedagogical knowledge differed based on respondents' major (Science, Mathematics, and Elective). Based on Table 4, the results revealed no statistically significant differences among the three groups for any of the constructs: STEM Integration Knowledge (F = 1.07, p = .346), STEM Pedagogical Strategies (F = 1.09, p = .340), STEM Lesson Design Knowledge (F = 2.54, p = .084), Technology Integration Knowledge (F = 2.25, p = .111), and STEM Assessment Knowledge (F = 0.91, p = .404). These findings suggest that students' academic major does not significantly influence their level of STEM pedagogical knowledge.

Similarly, one-way ANOVA results showed that respondents' STEM pedagogical expertise was not substantially impacted by their academic major (science, mathematics, or elective) (p >.05). These results imply that respondents' STEM pedagogical knowledge is consistently high, irrespective of their academic specialization or gender.

Table 4: Differences in STEM pedagogical knowledge by respondents' major (science, mathematics, and elective)

Construct	Science Mean	Math Mean	Elective Mean	F	p-value	Interpretation
SPK1: STEM Integration Knowledge	4.23	4.07	4.00	1.07	0.346	Not significant
SPK2: STEM Pedagogical Strategies	4.25	4.11	4.00	1.09	0.340	Not significant
SPK3: STEM Lesson Design Knowledge	4.26	4.03	3.92	2.54	0.084	Not significant
SPK4: Technology Integration Knowledge	4.33	4.09	4.18	2.25	0.111	Not significant
SPK5: STEM Assessment Knowledge	4.12	3.97	3.97	0.91	0.404	Not significant

4.4 Relationship Among STEM Pedagogical Knowledge Constructs

A Pearson correlation analysis was conducted to examine the relationships among the five constructs of STEM pedagogical knowledge. All constructions showed substantial positive relationships, according to the data (p <.001). Strong positive associations were found between STEM Integration Knowledge and STEM Pedagogical Strategies (r =.780), STEM Lesson Design Knowledge (r =.750), Technology Integration Knowledge (r =.683), and STEM Assessment Knowledge (r =.704).

Similar correlations were found between STEM Pedagogical Strategies and Technology Integration Knowledge (r =.808), STEM Lesson Design Knowledge (r =.798), and STEM Assessment Knowledge (r =.739). Additionally, there were significant positive correlations between STEM Lesson Design Knowledge and STEM Assessment Knowledge (r =.782) and Technology Integration Knowledge (r =.797).

Table 5: Relationship among STEM pedagogical knowledge constructs

Variable	SPK1	SPK2	SPK3	SPK4	SPK5	Interpretation
SPK1: STEM Integration Knowledge	1	.780**	.750**	.683**	.704**	Strong positive relationships
SPK2: STEM Pedagogical Strategies	.780**	1	.798**	.808**	.739**	Strong positive relationships
SPK3: STEM Lesson Design Knowledge	.750**	.798**	1	.797**	.782**	Strong positive relationships
SPK4: Technology Integration Knowledge	.683**	.808**	.797**	1	.797**	Strong positive relationships
SPK5: STEM Assessment Knowledge	.704**	.739**	.782**	.797**	1	Strong positive relationships

Pearson correlation coefficients are significant at p < .001 N = 114

Overall, the results show that there is a substantial correlation between the five dimensions of STEM pedagogical knowledge, indicating that respondents who exhibit greater knowledge in one dimension are likely to have higher knowledge in other related dimensions.

5. Discussion

This study determined the level of STEM pedagogical knowledge of pre-service teachers and investigated the influence of demographic factors such as gender and academic major on the knowledge of pre-service teachers. The findings revealed that pre-service teachers had a high level of STEM pedagogical knowledge in all five constructs, that is, STEM Integration Knowledge, STEM Pedagogical Strategies, STEM Lesson Design Knowledge, Technology Integration Knowledge, and STEM Assessment Knowledge.

The averages of the scores that were between 4.03 to 4.19 indicate that most of the respondents believed that they were well-informed about STEM pedagogy. These results suggest that pre-service teacher education programs have a significant role to play in equipping pre-service teachers with the pedagogical skills needed to support integrated STEM learning. The comparatively good levels of STEM pedagogical expertise in this study may have been because of the increasing focus of teacher training programs on STEM education. Recent studies have highlighted the importance of providing educators with the knowledge and the pedagogical skills required to successfully implement transdisciplinary STEM learning.

Margot and Kettler (2020), as an example, emphasized that teacher preparation programs that involve some exposure to STEM integration as well as sound pedagogical training can significantly raise the readiness of teachers to integrate STEM instruction in their classrooms. Thibaut et al. (2020) explain that pre-service teachers that receive structured training in STEM teacher methods demonstrate a better understanding and willingness to teach in any field. The mean score of Technology Integration Knowledge was the highest in all the characteristics considered in this study as it means that respondents are generally comfortable with the idea of using technology in STEM education. This finding agrees with earlier researchers that digital means have become an essential component of modern STEM education.

According to Falloon (2020), to improve the inquiry-based learning, collaboration, and problem-solving skills of students, it is essential that teachers use more digital tools in their teaching programmes in STEM. Moreover, Backfisch et al. (2021) realized that when acquiring strong technology pedagogical competencies, pre-service teachers are in a better position to deliver creative and student-centered learning experiences. These findings suggest that the respondents of the present study could have been aided by the exposure to the technology-integrated instructional practices during their teacher preparation.

The outcomes of the independent samples t-test showed that there were no statistically significant differences in male and female respondents in all five constructs of STEM pedagogical knowledge. This observation implies that gender does not have a major effect on the degree of pedagogical knowledge associated with STEM among pre-service teachers. Equivalent results have been established in the recent research conducted on gender disparities in STEM education abilities. As an example, Cheng et al. (2022) discovered that male and female pre-service teachers tend to exhibit similar degrees of pedagogical knowledge and attitude towards teaching STEM in case they are provided with equivalent training opportunities. This could point to the fact that gender-neutral learning opportunities are made available by the teacher education programmes to foster the growth of professional competencies irrespective of gender.

On the same note, the one-way ANOVA outcomes showed no statistically significant difference in STEM pedagogical knowledge amongst the respondents of various academic majors, that is, Science, Mathematics, and Elective programmes. This observation implies that the teacher education programmes can offer comparatively homogenous exposure to the STEM pedagogical ideas in the various disciplines. According to English (2021), integrated STEM education necessitates teachers to adopt cross-disciplinary pedagogical knowledge to help learners to have meaningful learning experiences. So, teacher education programmes tend to provide all pre-service teachers with basic STEM pedagogical skills irrespective of their academic background.

The correlation analysis has shown that the five dimensions of STEM pedagogical knowledge have strong positive relationships, and this shows that the constructions are very much interrelated. The findings indicate that educators that show more expertise in a particular dimension of STEM pedagogy are also more likely to have competencies in other areas connected to it. More specifically, the close connection between STEM pedagogical planning and technology integration knowledge underlines the significance of using digital tools to add to the instructional strategies in the process of successful STEM learning. These results align with other studies that show that STEM teaching demands that teachers have a set of pedagogical knowledge, technological proficiency, and interdisciplinary teaching ability (English, 2021; Margot and Kettler, 2020). Combined, the results of this research can offer some significant information about the growth of STEM pedagogical knowledge among pre-service teachers.

First, the degree of knowledge of all constructs is high, which implies that teacher education programmes can be successfully equipping future teachers to institute STEM teaching methods. Second, the fact that there are no notable gender and academic major differences implies that pre-service teachers are getting comparably consistent training experiences among the dissimilar demographical groups and disciplinary experiences. Third, the high correlation between the constructs proves the fact that successful STEM pedagogy implies an overall combination of competencies, not the domains of knowledge.

Although the outcomes of the research are positive, it is noteworthy that the presence of pedagogical knowledge does not necessarily mean effective implementation in classrooms. Past studies have revealed that pre-service teachers can face difficulty when using the STEM teaching strategies in the actual classroom setting. As an example, Thibaut et al. (2020) have pointed out that some of the obstacles that teachers encounter include lack of teaching experience, inadequate instructional materials, challenges in incorporating interdisciplinary ideas into the lesson.

Thus, teacher education programmes ought to maintain the provision of opportunities for practical teaching experiences, collaborative learning and professional development to facilitate efficient implementation of STEM education. Overall, the research results of the study can be included in the increasing range of literature on the topic of STEM teacher education as they present empirical evidence on the amount of STEM pedagogical knowledge among pre-service teachers. The findings also emphasize the need to enhance STEM-based pedagogical training in the teacher training programmes to make the future teachers better equipped to integrated STEM learning in schools.

6. Conclusion

This research explored the amount of STEM pedagogical knowledge of pre-service teachers and whether demographic variables like gender and academic major have any effect on the knowledge of pre-service teachers. The results showed that the respondents exhibited a high degree of STEM pedagogical understanding in all the five constructs, which shows that pre-service teachers are well equipped in terms of pedagogical underpinnings of teaching methodologies using STEM practices.

The reliability test was done to ascertain that the instrument employed in this study had very high internal consistency, meaning that the questionnaire was a good instrument in measuring STEM pedagogical knowledge among pre-service teachers. Moreover, the independent samples t-test and one-way ANOVA outcomes revealed that there was no significant difference between genders and academic major on the level of STEM pedagogical knowledge, which indicates that pre-service teachers of various backgrounds have similar levels of pedagogical competency. In general, the results show that teacher education programmes play a significant role in equipping future educators to teach students integrated STEM.

Although pre-service educators seem to be knowledgeable in their pedagogical knowledge, more focus should be placed on real practices of teaching and classroom utilization since it can reinforce further the aspect of implementation of STEM teaching in schools. To sum up, this research will enhance the existing literature on STEM teacher education by offering solid empirical data on how pre-service teachers are ready to use STEM pedagogy. Enhancing pedagogical training centered on STEM in teacher training programmes will continue to be fundamental in equipping teacher trainees with new models to facilitate innovative, inquiry based and interdisciplinary learning in educational institutions.

Regardless of the useful information presented in this study, it is important to note some limitations. To begin with, the research followed a cross-sectional survey research design, which assesses the perception of respondents at one moment in time and thus, it would not be feasible to determine the variation in STEM pedagogical knowledge over time. Second, the information was gathered because of a self-reported questionnaire, and this can impose bias in responses because a respondent can exaggerate his or her knowledge or competencies. Third, it was conducted on pre-service teachers in a particular teacher educator, and as such, it might not apply to other teacher education institutions or educational situations. Also, the research analyzed pedagogical knowledge but did not directly test the actual application of the STEM teaching practice in the classroom. Further studies can thus consider classroom observations, practicum studies or mixed methods to gain a deeper insight into the implementation of STEM pedagogical knowledge in practice.

This study offers several important implications for teacher education and STEM pedagogy. The findings highlight the need for teacher education programmes to move beyond theoretical instruction by strengthening the integration of theory and practice through structured practicum experiences, guided mentoring, and reflective learning opportunities. Institutions such as IPGKSAH can use these insights to refine curriculum design, ensuring that pre-service teachers are better supported in applying pedagogical knowledge in real classroom contexts. The identification of challenges and enabling pathways also underscores the importance of providing sustained institutional support, including access to teaching resources, collaborative learning environments, and continuous professional development. Furthermore, the study informs policymakers and educators on the necessity of aligning training programmes with classroom realities, particularly in promoting inquiry-based and learner-centered STEM practices. Overall, the findings contribute to enhancing the quality of STEM teacher preparation and support the broader goal of developing competent, confident, and adaptive educators capable of meeting the demands of 21st-century education.

Future studies can further build on the findings of this paper by delving into other variables that affect the quest to develop and implement STEM pedagogical knowledge in pre-service teachers. Longitudinal research might also be undertaken to test the development of STEM pedagogical competences during training programs of teachers as well as initial teaching practice. Also, qualitative designs like interviews or classroom observations can give more information on how pre-service teachers practice what they have learned in classrooms. Other areas of future research could also investigate how experience in teaching, institutional support, professional learning opportunities, and access to teaching materials in STEM area influence the capacity to teach integrated STEM. It could also be beneficial to expand the study to consider several teacher education institutions or regions to enhance the generalizability of the findings and give a larger picture of the STEM teacher preparation in other educational settings.

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