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Secondary school teachers' perceptions of STEM pedagogical content knowledge

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Abstract

Preparing students with knowledge and expertise in science, technology, engineering, and mathematics (STEM) is vital in meeting the demand for digital age career opportunities. Nevertheless, there is sparse research on teachers' views of student preparedness and teachers' knowledge of STEM in classroom instruction. The present study examines secondary school teachers' perceptions of STEM pedagogical content knowledge (STEMPCK). An online survey was administered to 66 Malaysian secondary school teachers through Google Forms to determine their perspectives of STEMPCK. Data were collected and analyzed using IBM SPSS Statistics Version 20.0. The descriptive analysis showed that the selected teachers highly agreed on the pedagogical knowledge and knowledge of 21st century skill components of STEMPCK. However, the non-parametric analysis showed no significant mean differences in STEMPCK scores based on gender, educational qualification, and teaching experience. The study's implications suggest that teachers in these fields should be equipped with the necessary knowledge to be more confident in implementing STEM teaching in their respective schools.

Keywords: 21st Century Skills, Secondary Schools, STEM Pedagogical Content Knowledge, Teacher Knowledge, Teaching Practices

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The swift innovations occurring during the 21st century have influenced the global socioeconomic landscape and the acceleration of knowledge based on the mobile internet, the Internet of Things, and big data (Allam, 2020). In addressing these challenges, the world needs a talented new generation to adapt to rapid technological development (Allam, 2020; Topcu, 2020). Managing technological developments to achieve the fourth industrial revolution (4IR) prepares future generations with the necessary knowledge of 21st century skills (Chuang, 2020; Schwab, 2019; Topcu, 2020). Demand for science, technology, engineering, and mathematics (STEM) is increasing in most countries around the world because of the swift development of the 4IR (Zaza et al., 2020). Therefore, a nation's competitiveness depends on STEM human capital in line with the 4IR.

Placing an emphasis on STEM topics is one of the main agendas of many educational systems

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(Attard et al., 2020; Topcu, 2020). Human capital development plans and educational qualifications are essential to attain the 4IR (Chuang, 2020; Topcu, 2020). Many strategic projects have been carried most developed countries, such as the United States, the United Kingdom, China, France, Russia, and Australia (Hossain & Robinson, 2012). These curriculum agendas were established to equip future generations with STEM skills, enabling them to compete internationally in the science and technology industry (Attard et al., 2020; Schwab, 2019). STEM education is a platform on which a country can compete internationally (Attard et al., 2020; Hossain & Robinson, 2012). The involvement of students in STEM at the secondary school level motivates them to explore STEM domains by furthering their studies in tertiary institutions (Evans et al., 2020; Kaleva et al., 2019; Siregar et al., 2019; Wells, 2013). Students who venture into STEM will be a resource in the workforce that can compete and contribute to their country in the future (Younes et al., 2020).

The Programme for International Student Assessment (PISA) 2018 results demonstrated that, across the Organization for Economic Co-operation and Development (OECD) countries, for mathematics and science, 76% and 78% of students, respectively, attained a score of Level 2 or higher. These students were on average 15 years old and could at a minimum interpret and recognize, without instructions, how a simple situation can be presented mathematically. In science, at a minimum level, students managed to recognize the correct explanation for familiar scientific phenomena and use such knowledge to identify, in simple cases, whether a conclusion was valid based on the data provided. The PISA 2018 report also stated that teachers' attitudes and practices across 43 educational systems in OECD countries resulted in higher student achievement in reading, mathematics, and science. Student enjoyment in learning the three literacies depended on teachers' enthusiasm for solid and positive teaching practices (Al Salami et al., 2017; Kennedy & Odell, 2014; Maass et al., 2019). Thus, STEM teachers' roles are vital in implementing STEM education because they are the mainstay and driving force in using appropriate instructional design to provide a suitable learning environment for students (Allen et al., 2016; Ayar, 2015; Honey et al., 2014; Kelley et al., 2020).

Pedagogical Content Knowledge for Teaching STEM

The initiatives for strengthening STEM education involve teachers. By continuously providing programs for retraining through professional development, workshops, symposiums, colloquiums, and discourse, teachers can increase their competencies, knowledge, skills, abilities, teaching approaches, and understanding of the content for their students (Burrows et al., 2021; Faikhamta et al., 2020; Gardner et al., 2019; Giamellaro & Siegel, 2018; Guzey et al., 2016; Ketelhut et al., 2020; Lau & Multani, 2018; Shernoff et al., 2017; Vossen et al., 2019; Yıldırım & Türk, 2018). Thus, the utilization of knowledge provided by teachers as facilitators and learning assistants provides opportunities for students to learn meaningfully (Song, 2019).

The potential for teachers to deliver and convey STEM content depends on teachers' pedagogical content knowledge (PCK) and STEM knowledge (Alonzo & Kim; 2015; Ayar, 2015; Aydin-Gunbatar et al., 2020; Rahman, Rosli, & Rambely, 2021a, 2021b). Practical application of knowledge in a form related to students' daily lives encourages student interest in STEM and hopefully develops students who can meet the demand for future STEM human resources (Al Salami et al., 2017; Attard et al., 2020; Faikhamta et al., 2020; Maass et al., 2019; Rahman, Rosli, & Rambely, 2021a; Siregar et al., 2019; Song, 2019). Using one discipline as a tool for teaching two disciplines may appear simple from ordinary teaching and learning processes for mathematics teachers. Teaching mathematical concepts sometimes requires science, such as heat absorption, light reflection, photosynthesis, or a green environment. However, teaching with integrated STEM refers to something more intentional and specific. STEM education may be enhanced by integrating it with other academic subjects, such as language arts, social studies, language, and the arts (Sanders, 2009, 2012; Wells, 2013). Educators must encourage students to participate in engineering design and thought by developing and exploring technologies in a manner that requires deep learning and application of mathematics and science as well as a consideration of other disciplines, for example, social science, English, or language arts (Abdurrahman, 2019; Moore et al., 2015; Nguyen, 2020; Sanders, 2012). Technology education integrates mathematics and science into design-based activity (Sanders, 2012; Wells, 2013). According to Vossen et al. (2019), teachers need PCK to outline a STEM-based lesson plan, implement it, and engage students in design-based activities using mathematical and scientific knowledge, which develops necessary and relevant skills.

Teachers can reinforce student learning across all four subjects in STEM through a multidisciplinary approach. Integrated STEM PCK demands proficiency in effectively blending engineering and other disciplines while teaching and learning STEM concepts (Lau & Multani, 2018). When teachers lack STEM PCK, sustained professional development programs can better prepare them for teaching integrated disciplines to boost student interest (Rahman, Rosli, & Rambely, 2021a). By applying integrated STEM pedagogical strategies, teachers are able to motivate students using mathematics, science, and engineering concepts in designing, making, and evaluating solutions to problems (Moore et al., 2015; Sanders, 2012; Wells, 2013).

Many scholars firmly believe that teaching STEM with strong PCK is vital to delivering the necessary knowledge effectively. It is important to note that PCK is a remarkable amalgam of content and pedagogy that is uniquely the province of teachers and comprises knowledge of the representations helpful in teaching a subject and the knowledge of (mis)conceptions and difficulties with the subject commonly experienced by learners (Shulman, 1987). PCK is the teacher's ability to employ the subject matter knowledge in a more comprehensible form for students (Aydin-Gunbatar et al., 2020). PCK can be divided into two categories: personal and collective (Gess-Newsome, 2015). Personal PCK is specifically about the teacher and is expanded by a teacher's personal experience, whereas collective PCK is molded by a set of teachers (Carlson & Daehler, 2019). Alternatively, PCK is discussed as declarative versus dynamic (Alonzo & Kim, 2015). Declarative PCK occurs when the knowledge is used to plan the instruction, while dynamic PCK is when the teacher utilizes the knowledge throughout the teaching process. Additionally, Lee and Luft (2008) framed PCK as the knowledge used to differentiate scientists from science teachers, whereas Nind (2020) posited that PCK differentiates researchers from teachers of research methods. Perhaps most importantly, PCK requires sufficient knowledge of many subject areas as well as adequate interdisciplinary skills (Çinar et al., 2016). PCK is also considered the act of expressing subject content as students learn (Depaepe et al., 2013). Furthermore, PCK assists teachers in broadening beyond mathematics or science by explaining and determining engineering problems and dealing with and improving designs for students (Hudson et al., 2015; Lau & Multani, 2018).

Effectiveness in implementing a STEM approach depends on adequate pedagogical knowledge, content knowledge, and occupational knowledge among pre-service and in-service teachers (Faikhamta et al., 2020; Rahman, Rosli, & Rambely, 2021a, 2021b; Yıldırım, 2016). After interviewing 28 middle school science and mathematics teachers, Yıldırım and Türk (2018) reported they felt that knowledge of integration, context, pedagogy, STEM, and 21st century skills was necessary in order to be good at teaching STEM topics effectively. Therefore, Yıldırım and Şahin (2019) developed a tool for measuring teachers' STEMPCK: the STEM Pedagogical Content Knowledge Scale

(STEMPCK Scale). The STEMPCK Scale consists of six factors: 21st century skills, pedagogical knowledge, mathematics, science, engineering, and technology. Therefore, based on the prior research, this study examines selected secondary school teachers' perceptions into STEMPCK based on their demographics. The research questions framing this study are as follows:

1. What are secondary school teachers' perceptions toward STEMPCK?
2. To what extent are there differences in secondary school teachers' perceptions into STEMPCK based on demographic variables, such as gender, educational qualification, and teaching experience?

METHODS

When examining teachers' perceptions into STEMPCK, this study utilized a survey research design for data collection. Participants were limited to secondary school teachers with at least five years of teaching STEM subjects in certain states of Malaysia. The data were gathered through 66 STEM secondary school teachers who volunteered to take part in the survey, as displayed in Table 1. Most of the participants are female (77.3%), ages ranging from 31– 40 years old (50%). In addition, the majority (50%) have a bachelor's degree and have been teaching for 11– 20 years.

Table 1. Demographic Profile of the Respondents

Demographic profile	Respondents	Frequency	Percentage
Gender	Female	51	77.3
	Male	15	22.7
Age	51-60 years old	10	15.2
	41-50 years old	23	34.8
	31-40 years old	33	50
Educational qualification	Masters	19	28.8
	Bachelors	47	71.2
Teaching experience	>30 years	6	9.1
	21-30 years	14	21.2
	11-20 years	33	50
	1-10 years	13	19.7

The STEMPCK Scale instrument was adapted from Yıldırım and Şahin (2019), consisting of 56 items measuring teachers' perceptions on three major aspects: (a) pedagogical knowledge (12 items), (b) STEM knowledge (science – 8 items), (technology – 7 items), (engineering – 7 items), (mathematics – 8 items), and (c) 21st century skills knowledge (14 items). The items utilized a 5-point Likert scale (1 = *strongly agree*, 2 = *agree*, 3 = *neutral*, 4 = *disagree*, 5 = *strongly disagree*) to represent secondary school teachers' perceptions into STEMPCK. We strongly believe that the STEMPCK Scale is a vital instrument for identifying what teachers know in general and what they do not know about teaching practices for STEM disciplines. The content of the scale is suitable for elementary, middle, and high school pre-service and in-service teachers. The instrument was distributed conveniently for two months to the STEM Teachers Association members through an online Google Forms document (http://gg.gg/STEM-PCK-1). Two experts validated the content and language translation of the instrument. The reliability analysis showed that the normalization value, that is, skewness (.74) and kurtosis (-.14), satisfied the value $p = \pm 1$ and the homogeneity value $p = .83$ ($p > .05$). In addition, the Cronbach's alpha value was .98 (a value of more than .90 indicates high reliability; Streiner, 2003). Thus, the instrument is considered valid and highly reliable for examining secondary school teachers' opinions of STEMPCK.

The raw data from the Google Forms document were entered into IBM SPSS Statistics version 20.0. Then, the collected data were analyzed descriptively, obtaining the sum of scores, frequency, percentage, median, mean, and standard deviation. These values were used to determine secondary school teachers' perceptions toward STEMPCK (research question 1). Meanwhile, we ran non-parametric analyses of Mann-Whitney and Kruskal-Wallis tests for examining the differences in teachers' perceptions into STEMPCK based on their gender, educational qualification, and teaching experience (research question 2).

RESULTS AND DISCUSSION

Secondary School Teachers' Perceptions Into STEMPCK

The secondary school teachers' perceptions into the components in the STEMPCK Scale instrument consist of pedagogical knowledge, STEM knowledge, and 21st century skills knowledge. The results revealed secondary school teachers' perceptions of STEMPCK with an overall mean of 2.62 (*SD* = 1.13). Table 2 outlines the descriptive statistics analysis on the STEMPCK Scale with the three main aspects of pedagogical knowledge (M_{PK} = 2.37), STEM knowledge ($M_{SCIENCE}$ = 2.91; $M_{TECHNOLOGY}$ = 2.70; $M_{ENGINEERING}$ = 2.63; $M_{MATHEMATICS}$ = 2.81), and 21st century skills knowledge (*M* = 2.34).

Table 2. Descriptive Statistics on STEMPCK

Construct	Mean	Standard Deviation
Pedagogical knowledge	2.37	1.04
Science	2.91	1.08
Technology	2.70	0.93
Engineering	2.63	0.90
Mathematics	2.81	1.17
21st century skills knowledge	2.34	1.13
STEM PCK	**2.62**	**1.13**

A lower mean score value indicates a high level of agreement in teachers' perceptions of the construct in this study. The lowest mean in the STEMPCK scale was for 21st century skills knowledge (M = 2.34; *SD* =1.13). The 21st century skills are necessary for solving real-life problems, and this study's results show high agreement on this construct among the selected teachers. It should be noted that the highest mean was for science (M = 2.91; *SD* = 1.08), one of the complex STEM disciplines that includes biology, physics, and chemistry.

STEMPCK Based on Pedagogical Knowledge

As displayed in Table 3, the STEMPCK Scale instrument includes 12 items to measure teachers' perceptions into the pedagogical knowledge construct. Most of the construct items showed a high agreement among teachers (between 10% to 56% for each category), which supported the results presented in Table 3 with a low mean score value. For example, item 5, "I can create an effective learning environment in the classroom," had a 75.8% agreement from the participants. Interestingly, we found that item 11, "I can teach quality and efficient lessons," had the lowest percentage of agreement, with 70% of the teachers disagreeing or strongly disagreeing with this item.

Table 3. Responses for Pedagogical Knowledge

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can use more than one teaching strategy, method, and technique in teaching a lesson.	17 (25.8)	31 (47)	7 (10.6)	5 (7.6)	6 (9.1)
2. I can guide students in every aspect.	13 (19.7)	28 (42.4)	12 (18.2)	9 (13.6)	4 (6.1)
3. I can help students in their research studies.	11 (16.7)	30 (45.5)	15 (22.7)	6 (9.1)	4 (6.1)
4. I can use alternative measurement and evaluation approaches.	7 (10.6)	35 (53.0)	14 (21.2)	7 (10.6)	3 (4.5)
5. I can create an effective learning environment in the classroom.	13 (19.7)	37 (56.1)	5 (7.6)	8 (12.1)	3 (4.5)
6. I can communicate effectively with students.	17 (25.8)	31 (47.0)	6 (9.1)	5 (7.6)	7 (10.6)
7. I can motivate students to learn courses.	22 (33.3)	25 (37.9)	7 (10.6)	3 (4.5)	9 (13.6)
8. I can determine whether the students have achieved their goals.	8 (12.1)	33 (50.0)	12 (18.2)	11 (16.7)	2 (3.0)
9. I can give students feedback and correction about the course.	15 (22.7)	33 (50.0)	4 (6.1)	6 (9.1)	8 (12.1)
10. I am qualified enough about how to evaluate students.	13 (19.7)	28 (42.4)	16 (24.2)	3 (4.5)	6 (9.1)
11. I can teach quality and efficient lessons.	6 (9.1)	7 (10.6)	7 (10.6)	38 (57.6)	8 (12.1)
12. I can teach lessons according to class level.	12 (18.2)	33 (50.0)	7 (10.6)	7 (10.6)	7 (10.6)

Note: Number of responses in frequency and percentage (parentheses).

STEMPCK Based on Science

The STEMPCK Scale instrument includes eight items measuring teachers' perceptions of STEM knowledge within the science construct. Participants had a high frequency of neutrality or disagreement with many of the items on this construct. The high mean value for this construct is supported through the item responses illustrated in Table 4. Item 6, "I can do advanced studies in science," accounted for the lowest percentage of agreement, with only 33% of participants agreeing or strongly agreeing with the statement. The highest frequency of agreement, with a total of 48.5%, was for item 7, "I encourage students to use science concepts."

Table 4. Responses for Science

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I have enough knowledge to teach science.	6 (9.1)	19 (28.8)	21 (31.8)	11 (16.7)	9 (13.6)
2. I follow the current developments and trends in the science field.	9 (13.6)	19 (28.8)	21 (31.8)	10 (15.2)	7 (10.6)
3. I can call students' attention to the course subject by asking science questions.	6 (9.1)	24 (36.4)	21 (31.8)	10 (15.2)	5 (7.6)
4. I can teach concepts, knowledge, theories, and laws of science.	5 (7.6)	22 (33.3)	22 (33.3)	8 (12.1)	9 (13.6)
5. I think that I will be effective in science education.	6 (9.1)	18 (27.3)	22 (33.3)	10 (15.2)	10 (15.2)

Table 4. (continued)

6. I can do advanced studies in science.	4 (6.1)	18 (27.3)	23 (34.8)	11 (16.7)	10 (15.2)
7. I encourage students to use science concepts.	6 (9.1)	26 (39.4)	16 (24.2)	10 (15.2)	8 (12.1)
8. I think that I am interested in a science course.	12 (18.2)	14 (21.2)	17 (25.8)	14 (21.2)	9 (13.6)

Note: Number of responses in frequency and percentage (parentheses).

STEMPCK Based on Technology

The STEMPCK Scale instrument includes seven items measuring STEM knowledge within the technology construct. The patterns of teachers' responses for technology (see Table 5) are similar to the science component for which many teachers preferred the neutral option when answering, which accounted for 19.7% to 43.9% of responses for the technology items. Item 2, "I can use technological tools in class," had the highest percentage of agreement (62.3%), followed by item 4, "I follow the current developments in technology," with 59.1%.

Table 5. Responses for Technology

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I have enough knowledge to teach technology.	6 (9.1)	20 (30.3)	25 (37.9)	12 (18.2)	3 (4.5)
2. I can use technological tools in class.	11 (16.7)	30 (45.5)	13 (19.7)	6 (9.1)	6 (9.1)
3. I have enough knowledge to integrate technology into different courses.	6 (9.1)	25 (37.9)	22 (33.3)	9 (13.6)	4 (6.1)
4. I follow the current developments in technology.	7 (10.6)	32 (48.5)	15 (22.7)	5 (7.6)	7 (10.6)
5. I can find new and different solutions to technological problems.	4 (6.1)	24 (36.4)	27 (40.9)	7 (10.6)	4 (6.1)
6. I know about different technologies.	4 (6.1)	25 (37.9)	22 (33.3)	11 (16.7)	4 (6.1)
7. I can link different disciplines with technology.	4 (6.1)	23 (34.8)	29 (43.9)	7 (10.6)	3 (4.5)

Note: Number of responses in frequency and percentage (parentheses).

STEMPCK Based on Engineering

The STEMPCK Scale instrument includes seven items measuring teachers' perceptions of STEM knowledge within the engineering construct. The teacher responses in Table 6 concerning engineering present some uneven distributions across the Likert scale categories. For example, item 2, "I think that I could help students in engineering education," item 3, "I follow the current developments in engineering," and item 7, "I can combine my courses in engineering education," had the highest frequencies of agreement and neutrality. Specifically, item 7 had 39.4% and 34.8% of participant responses in the *agree* and *neutral* categories, respectively.

Table 6. Responses for Engineering

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I think that engineering is based on science and mathematics.	17 (25.8)	29 (43.9)	6 (9.1)	7 (10.6)	7 (10.6)
2. I think that I could help students in engineering education.	6 (9.1)	22 (33.3)	22 (33.3)	12 (18.2)	4 (6.1)
3. I follow the current developments in engineering.	3 (4.5)	22 (33.3)	24 (36.4)	13 (19.7)	4 (6.1)
4. I think that technology is the application area of engineering.	11 (16.7)	35 (53.0)	8 (12.1)	8 (12.1)	4 (6.1)
5. Work activities related to engineering make me feel good.	5 (7.6)	31 (47.0)	15 (22.7)	12 (18.2)	3 (4.5)
6. I think that engineering is fun.	8 (12.1)	27 (40.9)	19 (28.8)	9 (13.6)	3 (4.5)
7. I can combine my courses in engineering education.	4 (6.1)	26 (39.4)	23 (34.8)	9 (13.6)	4 (6.1)

Note: Number of responses in frequency and percentage (parentheses).

STEMPCK Based on Mathematics

Table 7 displays teacher responses for the mathematics content across eight items, demonstrating diverse agreement across all categories. For instance, item 3, "I encourage students to use mathematics concepts," was rated at the top with the highest frequency (40 out of 66; 60.6%) of teacher responses in the strongly agree and agree categories. In contrast, 20 teachers (30.3%) indicated neutral for item 1, "I have enough content knowledge in mathematics," giving this item the highest percentage under the *neutral* category. This demonstrates that many teachers were unsure whether they possessed adequate mathematical content knowledge. Two items with the lowest frequency of agreement (28 responses) were item 4, "I can do advanced studies in mathematics," and item 6, "I have the skills and qualifications necessary for teaching mathematics." Many items were highly scored under the strongly agree, agree, and *neutral* categories.

Table 7. Responses for Mathematics

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I have enough content knowledge in mathematics.	10 (15.2)	19 (28.8)	20 (30.3)	10 (15.2)	7 (10.6)
2. I believe that I can teach concepts, theorems, and theories in mathematics lessons effectively.	9 (13.6)	23 (34.8)	17 (25.8)	6 (9.1)	11 (16.7)
3. I encourage students to use mathematics concepts.	12 (18.2)	28 (42.4)	12 (18.2)	5 (7.6)	9 (13.6)
4. I can do advanced studies in mathematics.	8 (12.1)	20 (30.3)	17 (25.8)	13 (19.7)	8 (12.1)
5. I think that mathematics is a discipline with terms and theories.	8 (12.1)	26 (39.4)	17 (25.8)	5 (7.6)	10 (15.2)
6. I have the skills and qualifications necessary for teaching mathematics.	11 (16.7)	17 (25.8)	16 (24.2)	8 (12.1)	14 (21.2)
7. I know how to use mathematics and science together.	8 (12.1)	23 (34.8)	12 (18.2)	14 (21.2)	9 (13.6)

Table 7. (continued)

8. I follow the developments in mathematics.	11 (16.7)	18 (27.3)	16 (24.2)	10 (15.2)	11 (16.7)

Note: Number of responses in frequency and percentage (parentheses).

STEMPCK Based on 21st Century Skills Knowledge

Specifically, Table 8 shows four items had very high frequencies of agreement: "I can communicate effectively with my friends" (item 3), "I can do group work with my friends" (item 5), "I respect my friends' thoughts" (item 7), and "I think that the problems have more than one solution" (item 14). Thus, it seems the teachers were able to work professionally with their colleagues. It is interesting to note that item 6, "I can make new and different designs," accounted for the highest number of responses under the *neutral*, *disagree*, and *strongly disagree* categories, with a frequency of 20 (30.3%).

Table 8. Responses for 21st Century Skills Knowledge

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I can improve the students' critical thinking skills.	11 (16.7)	34 (51.5)	9 (13.6)	6 (9.1)	6 (9.1)
2. I will help the students to develop the problem-solving skills necessary in their everyday life.	10 (15.2)	38 (57.6)	7 (10.6)	5 (7.6)	6 (9.1)
3. I can communicate effectively with my friends.	19 (28.8)	31 (47.0)	3 (4.5)	2 (3.0)	11 (16.7)
4. I can put myself in someone's place and empathize.	18 (27.3)	30 (45.5)	4 (6.1)	6 (9.1)	8 (12.1)
5. I can do group work with my friends.	22 (33.3)	28 (42.4)	2 (3.0)	5 (7.6)	9 (13.6)
6. I can make new and different designs.	8 (12.1)	26 (39.4)	20 (30.3)	7 (10.6)	5 (7.6)
7. I respect my friends' thoughts.	23 (34.8)	27 (40.9)	2 (3.0)	5 (7.6)	9 (13.6)
8. I can lead my friends.	15 (22.7)	30 (45.5)	10 (15.2)	6 (9.1)	5 (7.6)
9. I am tolerant of criticism.	19 (28.8)	30 (45.5)	6 (9.1)	4 (6.1)	7 (10.6)
10. I am sure that I will consider the views of others while making decisions.	14 (21.2)	34 (51.5)	4 (6.1)	5 (7.6)	9 (13.6)
11. I can help my friends improve their imagination.	14 (21.2)	31 (47.0)	11 (16.7)	4 (6.1)	6 (9.1)
12. I believe that I can set my own learning goals.	14 (21.2)	34 (51.5)	7 (10.6)	6 (9.1)	5 (7.6)
13. I am confident that I can manage my time wisely while working alone.	16 (24.2)	31 (47.0)	8 (12.1)	4 (6.1)	7 (10.6)
14. I think that the problems have more than one solution.	24 (36.4)	26 (39.4)	3 (4.5)	3 (4.5)	10 (15.2)

Note: Number of responses in frequency and percentage (parentheses).

The STEMPCK includes pedagogical knowledge, STEM knowledge, and 21st century skills knowledge (Yıldırım & Şahin, 2019). Teachers' knowledge of pedagogical content, STEM, and 21st century skills is essential in order to connect real-world situations from theory to practice, resulting in meaningful learning (Attard et al., 2020; Kennedy & Odell; 2014; Rahman, Rosli, Rambely, & Halim, 2021; Yıldırım & Türk, 2018). Knowledge proficiency in STEM will increase teachers' beliefs and enthusiasm, improving classroom instruction (Allen et al., 2016; Ayar, 2015; Aydin-Gunbatar et al., 2020; Guzey et al., 2016; Nguyen, 2020; Stohlmann et al., 2012; Sujarwanto & Ibrahim, 2019). Additionally, teacher involvement in STEM professional development can affect their teaching content, and ultimately the way they use their PCK to deliver STEM content (Faikhamta et al., 2020; Ketelhut et al., 2020). Teachers' preparedness to receive and engage with STEMPCK can them distinguish their teaching capability using an integrated STEM approach.

As vast technological advancements result in changes within educational systems, teachers also need to change their mindsets to adapt to new STEM curriculum content (Tunc & Bagceci, 2021). Acquiring new STEM knowledge requires teachers to explore their abilities to transfer theoretical knowledge into a practical form (Abdurrahman, 2019; Attard et al., 2020; Ayar, 2015; Kelley et al., 2020; Nguyen, 2020; Sujarwanto & Ibrahim, 2019). Teachers' understanding of new STEM education processes can inspire students to enter the STEM fields (Attard et al., 2020; Kennedy & Odell, 2014). Students' ability to use STEM in their lives helps to create meaningful learning (Attard et al., 2020; Kennedy & Odell, 2014). By exploring interactive and engaging real-world activities, students learn more about the nature of STEM within their world (Nguyen, 2020). However, considering the time required, teachers need to understand, interpret, practice, and apply integrated STEM content within classroom lessons (Burrows et al., 2021). As the role of education is a primary medium for teaching and learning using the STEM approach from theory to practice, it is undeniable that teachers are a mediator to cultivate the new generation of the STEM workforce (Allen et al., 2016; Ayar, 2015; Nguyen, 2020; Westaway et al., 2020).

It is worthwhile to focus future investigations on the challenges of using 4IR technologies and 21st century skills in STEM teaching and learning. For instance, a STEM project, MakerSpace, was introduced to secondary students for developing 21st century skills involving 4IR technologies. Teachers must develop appropriate competencies for this creative and innovative project to work, especially with regard to 21st century skills (Abdurrahman, 2019; Kinboon et al., 2019; Rahman, Rosli, Rambely, & Halim, 2021). Exploring teachers' capabilities to apply STEMPCK during the teaching process through an interview or an observation session in the classroom is also recommended for future research. The relationships between these content areas and other STEM disciplines provide opportunities for teachers to make multidisciplinary connections to the teaching approach and students' individual and social development (Çinar et al., 2016). Teachers could integrate STEM in other science content areas, such as life science, physical science, or earth science (Guzey et al., 2016). STEM teachers undertake many attempts to integrate these content areas in the classroom, as they believe in value-added knowledge (Sujarwanto & Ibrahim, 2019). Hence, to ease teaching and learning using the STEM approach in or out of the school environment, it is advisable for teachers to have a clear view regarding STEMPCK and to have sufficient knowledge regarding STEM (Ayar, 2015; Aydin-Gunbatar et al., 2020; Faikhamta et al., 2020; Nind, 2020). Teachers' knowledge in STEM is the catalyst for teachers inaugurating STEM practices within the school environment (Allen et al., 2016; Nguyen, 2020).

The analysis further examined the differences in secondary school teachers' scores on the STEMPCK based on demographic factors, such as gender, education qualification, and teaching experience (research question 2). Non-parametric analyses were performed to accommodate the assumption of the violation of the normality distribution. A Bonferroni-adjusted alpha level of .016 (.05/3) was applied to minimize the chances of false positive results from the multiple tests employed.

Differences in STEMPCK Based on Gender

The descriptive statistics in Table 9 present a slight difference in the median scores of STEMPCK perceptions between male (*Mdn* = 2.44) and female teachers (*Mdn* = 2.49). The results of the Mann-Whitney test indicated that this difference was not statistically significant (U [N_{male} = 15, N_{female} = 51] = 373, z = -0.15, p = .884).

Table 9. STEMPCK Based on Gender

Gender	N	Mean rank	Sum of ranks
Male	15	32.87	493
Female	51	33.69	1718

Differences in STEMPCK Based on Educational Qualification

For educational qualifications, the data in Table 10 display differences in the median scores of STEMPCK perceptions between teachers who hold a bachelor's degree (*Mdn* = 2.44) and those with a master's degree (*Mdn* = 2.81). However, the Mann-Whitney analysis showed that the difference was not statistically significant (U [$N_{bachelor}$ = 47, N_{master} = 19] = 349, z = -1.38, p = .167).

Table 10. STEMPCK Based on Educational Qualification

Educational qualification	N	Mean rank	Sum of ranks
Bachelor	47	31.43	1477
Master	19	38.63	734

Differences in STEMPCK Based on Teaching Experience

In this study, we discovered varied differences in the median scores of STEMPCK perceptions based on teaching experience. Nonetheless, the Kruskal-Wallis test indicated that the differences were not statistically significant: H(3) = 4.62, p = .20. Data in Table 11 show that teachers who had taught for more than 30 years had the highest mean score of 47.83. The results suggest that teachers with more experience in teaching possess higher agreement on items in the STEMPCK instrument. The second highest mean rank (36.23) was for teachers with less than ten years of teaching experience.

Table 11. STEMPCK Based on Teaching Experience

Teaching experience	N	Mean rank	Rank
1– 10 years	13	36.23	2
11– 20 years	33	31.64	3
21– 30 years	14	29.21	4
> 30 years	6	47.83	1

The current study results demonstrate that the demographic factors of gender, educational qualifications, and teaching experience did not significantly influence STEMPCK perceptions among the 66 secondary school teachers chosen from different states in Malaysia who participated in the study. Generally, men and women equally succeed in the STEM disciplines (Cheryan et al., 2017). The balanced suitability of both male and female teachers helps foster an educational space with instructors and professionals that can utilize differing skill sets to effectively address whatever challenges may arise in the classroom (Britton, 2017). STEM-based practices can be complemented by equity between genders, consequently attracting every student's attention and improving their capabilities equally (Attard et al., 2020).

Findings also suggest that teachers with higher qualifications are motivated to apply new knowledge and teaching approaches (Tunc & Bagceci, 2021; Vermote et al., 2020). This signifies that some experienced teachers would quickly adapt and adopt the new PCK strategies into their teaching practices. Utilizing their PCK, reflecting on the teaching process, and overcoming challenges can lead to adaptive teaching (Allen et al., 2016). On the other hand, novice teachers can update their knowledge and teaching skills with professional development and other related courses that can enhance their teaching potential (Allen et al., 2016). Nevertheless, teachers require extra time and support to gain confidence in balancing the knowledge and practical activities involved in teaching STEM (Burrows et al., 2021; Giamellaro & Siegel; 2018). The advantage of STEMPCK is that it provides teachers with confidence and motivation to teach within the classroom or other co-curricular activities. Unfortunately, during the pandemic of Covid-19, the teaching process was quite challenging within face-to-face settings. Thus, teachers should continuously refresh their knowledge by upgrading their digital and scientific proficiency and literacy within their teaching approaches.

CONCLUSION

The analysis and results showed that gender, educational qualification, and teaching experience did not significantly influence STEMPCK among the 66 secondary school teachers in different states of Malaysia who participated in the present study. The selected teachers had highly positive perceptions of STEMPCK relating to the components of pedagogical knowledge and 21st century skills knowledge but not to those of STEM knowledge. STEM develops gradually as a discipline and necessitates strong educational practices based on teacher PCK. The phenomena which contribute to declining participation in the STEM fields include (a) insufficient PCK of STEM, (b) teachers' incompetency regarding STEM pedagogies, (c) the perception of difficulty in integrating STEM disciplines, (d) a vague understanding and discomfort with teaching using the STEM approach, (e) students' low achievement in international assessment (PISA, 2018) due to low confidence in the STEM disciplines, and (f) less student interest in participating in STEM fields. However, these can be improved by creating a positive learning environment to boost STEM interest. Hence, support for teachers is vital in facing challenges and carrying out STEM in the classroom or through co-curricular activities. Improvement and development of in-service education for teachers related to STEM-based knowledge is a concern for theoretical knowledge. The authors agree with Yildrim's (2016) suggestion to implement multidirectional educational programs by using information, communication, and advancements in technology to encourage interaction among teachers, thereby facilitating the sharing of their self-improvement concerning STEM. Engaging with the PCK-based STEM professional development program recommended by Faikhamta et al. (2020) helped determine and enhance teachers' teaching ability using an integrated STEM approach. Through this research study, we have shown that teachers learn more about the nature of STEM through hands-on activities. Participation in the design and implementation of STEM lesson cycles with feedback from STEM experts and colleagues helps develop more effective STEM teaching. Applying STEM knowledge that is practically implemented in the teaching process is beneficial because, by advancing PCK, quality instructional advancement can be achieved.

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Declarations

Author Contribution	:	NAR: Conceptualization, Writing - Original Draft, Editing and Visualization. RR: Writing - Review & Editing, Formal analysis, and Methodology. NCS: Writing - Review & Editing, Formal analysis, and Methodology. ASR: Validation and Supervision. MMC: Validation and Supervision. RMC: Validation and Supervision.
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