Mathematical teachers' knowledge of STEM-based education

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Abstract. The challenge of the industrial revolution 4.0 (4IR) demands that future generations have high knowledge, skills, and capabilities in technology. A country's competitiveness depends on STEM human capital as 4IR develops. Therefore, more organized and holistic actions need to be taken to ensure that the STEM level of mastery is enhanced among students. High demand for STEM human capital is a challenge to most developed countries in the world. Teachers are a crucial medium in the implementation of STEM education in schools. Mastering the knowledge of teachers in STEM education will provide positive input to students' interest in learning. The purpose of this study was to identify the mathematics teacher's knowledge of STEM-based education. A quantitative study was conducted on 66 teachers who teach STEM subjects in high school. Twenty-three of them are math teachers. The findings show that these teachers know STEM education at a moderate level. The implications of this study indicate that the mastery of teachers' knowledge of STEM education will stimulate students' interest in STEM education. Future studies can explore the factors that influence teachers' knowledge of STEM education in terms of teacher preparation and in-service teacher professional development programs.

1. Introduction

Innovation and dissemination of knowledge based on mobile internet, public data, and Internet of Thing (IoT) have transformed the global socioeconomic landscape [1]. The culture of global economic change was influenced by the development of industrial revolution 4.0 (IR4.0) [2]. The impact of urbanization, demographic shifts, and new technology discoveries in most countries of the world has been affected. Human capital needs are a critical factor in ensuring a country's success in the fourth industrial revolution [3]. Human capital skilled in the application of disruptive technology and 21st-century skills are in high demand in the field of employment [4]. Human capital development plans, that meet current qualifications, need to be considered [3,4]. Most developed countries in the world such as the United States (USA), United Kingdom (UK), France, Russia, Finland, China, and Australia have developed strategic plans in Science, Technology, Engineering, and Mathematics (STEM) [5] [6]. Strengthening STEM education will ensure that these countries remain competitive internationally [4,5,6].

Malaysia does not miss out on strengthening STEM education gradually. Malaysia needs at least one million STEM workers, of whom 50 percent are highly skilled workers [7]. But the worrying thing is that there is a decline in student enrollment in the STEM field in high school [8]. One of the critical aspects of the fall is due to the poor quality of teaching and learning (T&L) process [7,8]. Besides, teachers do not encourage students to think critically, creatively, and innovatively [7,8]. A study conducted by the Education Policy Research and Development Division (EPRD), Ministry of Education in Malaysia also reveals that there is a need to improve the quality of teaching and learning in STEM subjects. The findings show that there is a need to improve the quality of teaching and learning in STEM subjects. The findings show that there is a need to improve the quality of teaching and learning in STEM subjects.
Education Malaysia (MOE) (2017), found that teachers' awareness of STEM education was only 29.9 percent [8]. In general, the results show that awareness levels of STEM are still low at all levels. As such, MOE has implemented several STEM education strengthening initiatives through the Malaysian Education Development Plan (PPPM) 2013-2025. Among the MOE initiatives that have been implemented since 2016 are (1) increasing student interest and awareness in STEM fields, (2) enhancing STEM teachers' skills, and (3) raising public awareness of STEM fields [8].

In ensuring that these objectives are met, teachers' ability to integrate STEM disciplines and creativity in their teaching strategies will encourage student enrollment in STEM fields [9,10]. Therefore, STEM subject teachers, especially among mathematics teachers, encouraged to know STEM pedagogical content (STEM PCK) [11] before implementing T&L STEM in the classroom or outside the school [12]. STEM PCK includes content knowledge (CK), STEM integration knowledge, pedagogical knowledge (PK), and 21st-century knowledge [11]. The mastery of knowledge in STEM education will give mathematics teachers confidence in implementing T&L STEM [10,11,13].

An article on STEM education analysis and meta-analysis [14] shows that teachers' effectiveness in STEM education depends on CK, their job knowledge, and STEM PCK. So to produce teachers who are knowledgeable and skilled in STEM education, the emphasis is on STEM PCK. Pre-service and in-service teachers need to be provided with the necessary knowledge and skills in STEM [11,15,16,17]. The adaptation of the STEM teaching process, emphasizes teachers who have good STEM PCK, use the T&L constructivism paradigm, and have the ability to create a vision. In contrast, teaching can overcome the challenges they face and can adapt to the teaching process [10]. Researchers have found that teachers who have undergone professional development early in their involvement in education can support the development of novice teachers to tailor their teaching and will be more effective [18,19,20].

2. Methods
This study used a quantitative method involving a population of 66 teachers teaching STEM subjects for the year 2020. This study used simple random sampling. Among them were 23 mathematics teachers. The researcher used and customized the STEM PCK scale questionnaire instrument by Yildrim and Sahin [11]. Questionnaires' content validity conducted by language expertise. This survey has 56 questions. The scales used were Likert Scale consisting of "Strongly Agree = 1", "Agree = 2", "No Opinion = 3", "Disagree = 4", and "Strongly Disagree = 5". The questionnaires consist of 3 main sections, which were pedagogical knowledge (12 items), STEM integration knowledge (Science - 8 items), (technology - 7 items), (engineering - 7 items), (mathematics - 8 items), and 21st-century knowledge (14 items). Data were analyzed using descriptive statistics involving frequency, percentage, mean, standard deviation, and independent-sample t-test. The researcher needed to meet the test assumptions of normality and homogeneity before ran the t-test analysis test. The test of assumption was a test of normality and homogeneity. Normalization test analysis used skewness and kurtosis. The analysis results were found to be $p = 0.544$ ($p = \pm 1$). Therefore, it concluded that the data distribution in this study normally distributed. While the test of homogeneity assumption based on Levene's test. The analysis results were found to be $p = 0.142$ ($p>0.05$). In that case, the test of homogeneity satisfactorily fulfilled.

3. Result and Discussion
Based on the findings of the study, there are differences in mathematical teachers' knowledge of STEM-based education (STEM PCK) for genders (Table 1). The mean score obtained by female teachers is higher than male teachers. It shows that female teachers are more interested in upgrading their knowledge and skills regarding STEM education. Female teachers are keener and presented in enhancing their STEM-based education [17,21,22].
Table 1. Mathematical teachers' knowledge of STEM-based education (STEM PCK) based on gender.

| Aspect       | Gender | Mean |
|--------------|--------|------|
| STEM PCK     | Male   | 2.50 |
|              | Female | 2.54 |

According to Table 1, the mean score values related to mathematical teachers' knowledge of STEM-based education were male (mean = 2.50) and female (mean = 2.54). This result concluded that the mean score of female teachers is higher than the mean score of male teachers with a score difference of 0.04. Therefore, the aspect of gender is one of the factors to be considered in influencing mathematics secondary school teachers towards STEM PCK.

On the other hand, looking at the aspect of teaching experience of mathematical teachers' knowledge also showed differences. The highest mean score obtains referred to the mathematics teacher with less than ten years of teaching. Due to vast technologies in the education system, lead young and energetic mathematics teachers to endeavor the knowledge and skill in T&L STEM education [13].

Table 2. Mathematical teachers' knowledge of STEM-based education (STEM PCK) based on teaching experience.

| Teaching experience | Mean | St. Dev |
|---------------------|------|---------|
| 1-10 years          | 2.67 | 1.23    |
| 11-20 years         | 2.44 | 1.12    |
| > 20 years          | 2.62 | 1.34    |

From Table 2, the mean score value for mathematical teachers' knowledge of STEM-based education (STEM PCK) based on teaching experience within 1-10 years (mean = 2.67), 11-20 years (mean = 2.44) and > 20 years (mean = 2.62). Therefore, the analysis found that teaching experience is not crucial for the teachers to enhance their knowledge in a particular field. New knowledge is needed to push mathematics teachers to explore STEM education in T&L. As the ministry of education embarked on the importance of STEM education, the teachers, especially in teaching STEM subjects, should take their effort and initiative to enroll any professional development offered by the government or non-profit government.

Furthermore, the mean score stated that there were differences in mathematical teachers' knowledge base from the categories in the STEM PCK Scale (Table 3). STEM PCK Scale consists of pedagogical knowledge, STEM integration knowledge (Science, technology, engineering, and mathematics) and 21st-century skills. From the data analyzed, its proven exist differences among the categories of the STEM PCK Scale.

From Table 3, the highest mean score of knowledge is Science (mean = 2.86), whereas the least mean score in Mathematics. This analysis concluded that mathematical teachers' knowledge of STEM-based education still needs to upskill. Even though this research is focusing on mathematics teachers, their mathematical knowledge integrating with three other subjects is still low compared to the other knowledge. As in reality, some teachers have holes in their subject content knowledge, therefore, asking them to teach another subject may create new knowledge gaps, challenges, and difficulties [10,23]. The integration of STEM will succeed if the teacher understands the subject matter and manages to conceptualize connections among subjects [9,13,17].
Table 3. Descriptive statistics on mathematical teachers’ knowledge STEM-based education (STEM PCK).

| STEM PCK                    | Mean | St. Dev |
|-----------------------------|------|---------|
| Pedagogical knowledge       | 2.41 | 1.27    |
| STEM Integration knowledge  | 2.86 | 1.03    |
| Science                     | 2.63 | 1.09    |
| Technology                  | 2.50 | 1.04    |
| Engineering                 | 2.37 | 1.41    |
| Mathematics                 | 2.38 | 1.35    |

4. Conclusion

This research only examined mathematics secondary school teachers based on sex, teaching experience, and categories of the STEM PCK Scale. Recommended in the future, the researchers identify mathematical teachers' knowledge of STEM-based education through teachers’ T&L STEM preparation and the necessity of professional development among in-service teachers to build up STEM knowledge and skill among other STEM field teachers.

Successful implementation of STEM education in school involved the participation of relevant authorities. Ministry of education, state education department, district education department, school administration, school staff, teachers, parents, parental and teachers’ association, and students have to play their role to fulfill the STEM education objectives. Referring aspect of teachers, even though there is a difference in mathematical teachers’ knowledge of STEM-based education on gender, teachers are still the utmost medium of transferring knowledge to students. The ability and willingness of the teachers in absorbing new knowledge, especially in STEM PCK will bring an improvement in their teaching and learning skills in the long run. To cope with the challenging and changing technologies in education, in-service teachers should play a role in upgrading the quality of teaching no matter he or she is experienced or inexperienced in his or her teaching field. Continuous in gaining the knowledge and skills in the teaching profession will give a kind of satisfaction of teaching among teachers. The advantages of having STEM-related skills and STEM knowledge, support the teachers to apply effective teaching methods. In the other hand, students with STEM literacy enable them to be innovative, inventive and integrating STEM to understand the problem, solving it by applying to the real-world context. Involvement in the STEM field among secondary school students is adequate preparation for future careers in the STEM workforce.

5. References

[1] Allam Z, 2020 Data as The New Driving Gears of Urbanization. In: Cities and the Digital Revolution Switzerland: Palgrave Pivot, Cham.
[2] Abd Halim S N and Abd Halim S N 2020 Employer’s Role Performance Towards Employees’ Satisfaction: A Study of SME Industry 4.0 in Malaysia. In Challenges and Opportunities for SMEs in Industry 4.0 IGI Global.
[3] Topcu M K 2020 Competency Framework for the Fourth Industrial Revolution. In Human Capital Formation for the Fourth Industrial Revolution IGI Global.
[4] Chuang S, 2020 An empirical study of displaceable job skills in the age of robots Eur. J. Train. Dev.
[5] Schwab K 2019 Insight Report - World Economic Forum.
[6] Marginson S Tytler R Freeman B and Roberts K 2013 STEM: Country comparisons international comparisons of science, technology, engineering and mathematics (STEM) education. Final report.
[7] Hamdan H 2017 Majlis Profesor Negara - Kongres Kebangsaan STEM Majlis Profesor Negara
[8] Laporan Pendidikan STEM 2017 Mesyuarat Majlis Sains Negara Bangunan Perdana Putra, Putrajaya.

[9] Kennedy T J and Odell M R L 2014 Engaging Students In STEM Education Sci. Educ. Int. 25 3 246–258.

[10] Allen M Webb A W and Matthews C E 2016 Adaptive Teaching in STEM: Characteristics for Effectiveness Theory Pract. 55 3 217–224.

[11] Yildirim B and Sahin T E 2018 STEM Pedagogical Content Knowledge Scale (STEMPCK): A Validity and Reliability Study J. STEM Teach. Educ. 53 2 1–20.

[12] Ayar M C 2015 First-hand experience with engineering design and career interest in engineering: An informal STEM education case study Educ. Sci. Theory Pract. 15 6 1655–1675.

[13] Stohlmann M Moore T and Roehrig G 2012 Considerations for Teaching Integrated STEM Education J. Pre-College Eng. Educ. Res. 2 1 28–34.

[14] Yildirim B 2016 An analyses and meta-synthesis of research on STEM education J. Educ. Pract. 7 34 23–33.

[15] Hume A and Berry A, 2011 Constructing CoRes-a Strategy for Building PCK in Pre-service Science Teacher Education Res. Sci. Educ. 41 3 341–355.

[16] Kelley T R Knowles J G Holland J D and Han J 2020 Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice Int. J. STEM Educ. 7 14.

[17] Attard C Grotenboer P Attard E and Laird A 2020 Affect and Engagement in STEM Education. In STEM Education Across the Learning Continuum Springer, Singapore.

[18] Guzey S S Moore T J and Harwell M 2016 Building up stem: An analysis of teacher-developed engineering design-based stem integration curricular materials J. Pre-College Eng. Educ. Res. 6 1.

[19] Çinar S Pirasa N Uzun N and Erenler S 2016 The effect of STEM education on pre-service science teachers’ perception of interdisciplinary education J. Turkish Sci. Educ. 13 Specialissue 118–142.

[20] Giamellaro M and Siegel D R 2018 Coaching teachers to implement innovations in STEM Teach. Teach. Educ. 76 25–38.

[21] Cheryan S Ziegler S A Montoya A K and Jiang L 2017 Why are some STEM fields more gender balanced than others? Psychol. Bull. 143 1 1–35.

[22] Britton D M 2017 Beyond the chilly climate: The salience of gender in women’s academic careers Gend. Soc. 31 1 5–27.

[23] English L D 2016 STEM education K-12: perspectives on integration Int. J. STEM Educ. 3 1 1–18.

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