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Correlation between STEM Knowledge and STEM Teaching Practice: A Study of Mathematics Teachers' Professional Development

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Abstract

This research aims to investigate the relationship between mathematics teachers' knowledge of STEM (Science, Technology, Engineering, and Mathematics) education and their teaching practice in schools during a STEM professional development program. The study involved 34 Indonesian mathematics vocational high school teachers enrolled in the STEM professional development program. Tests and reports on STEM teaching practices served as data sources for this study. Our finding shows a positive correlation between mathematics teachers' STEM knowledge and how they facilitate STEM project-based learning for their students. We discuss two different points of view to interpret this result. Furthermore, we suggest the need for further research to develop sustainable efforts in strengthening the STEM education interdisciplinary approach for the professional development of mathematics teachers.

Keywords: mathematics teachers' professional development program, project-based learning, STEM

INTRODUCTION

Cultivating students' career interests in the STEM workforce (Deming & Noray, 2020; Stevenson, 2014) requires teachers' professional development (TPD) to be accessible to all STEM teachers. The interdisciplinary paradigm in integrated STEM should enable teachers with expertise in the purity of specific knowledge to gain access to STEM education and the courage to reform their teaching practices. Mathematics teachers in Indonesia should not be exempt from this rule. The curriculum system in Indonesia still leaves a gap for mathematics teachers to develop their professionalism in an interdisciplinary manner to teach STEM (Marfuah, 2021). Mathematics's demanding role in single-subject learning to develop conceptual understanding, problem-solving, reasoning, and mathematical modeling skills presents a challenge for mathematics teachers to expand their interdisciplinary horizons in STEM learning that emphasizes design-thinking, creativity, and collaboration (Becker & Park, 2011; Marfuah, 2021; Sokolowski, 2018). For this reason, the need for a STEM professional development program, particularly for mathematics teachers in Indonesia, is unquestionable. Luft et al. (2020) claim that the TPD program that separates the respective disciplines of science, technology, engineering, and mathematics increases teachers' knowledge about STEM education and their teaching practices, although it may have limitations in presenting an interdisciplinary context.

Several studies examine preservice teachers' professional preparation in STEM education (Bergsten & Frejd, 2019; Berisha & Vula, 2021; Chai et al., 2020). TPD for in-service teachers, on the other hand, is critical because they may fall behind in STEM dissemination despite being at the forefront of the national education system. This issue is becoming increasingly broad due to the increasing demands for mathematics teachers to access STEM education. Teaching mathematics in a relevant, realistic, collaborative, and motivating way to students is an excellent opportunity for mathematics teachers to use their practice in STEM education (Maass et al., 2019; Marfuah, 2021). Hence we come to the question, is it true that teachers who better understand STEM education are better equipped to teach mathematics with STEM?

One of the issues in STEM education that necessitates teacher knowledge and skills is STEM learning models. Experts have developed many STEM learning models to be implemented in schools, one of which is STEM Project-Based Learning (STEM PjBL). STEM PjBL is contextual learning that requires students to solve problems and demonstrate mastery of STEM fields by solving ill-defined problems resulting in well-defined outcomes (Capraro et al., 2013). The STEM PjBL syntax consists of reflection, research, discovery, application, and communication.

There have been a number of investigations into the connection that exists between teachers' STEM knowledge and their teaching practice. Han et al. (2015) employ a qualitative case study to analyze the connection between in-service teachers' knowledge of STEM project-based learning and their implementation. Hasim et al. (2022) conducted a systematic literature review on the relationship between teachers' STEM knowledge and instructional practices. We also highlight that most studies examine STEM TPD in Indonesia from science teachers' perspectives (Nugroho et al., 2019; Parmin et al., 2020) rather than mathematics. In addition to the studies cited above, our research attempts to provide quantitative evidence about a STEM TPD from the perspective of mathematics teachers in Indonesia.

For this reason, we investigated a STEM TPD program for in-service vocational high school mathematics teachers (the setting of the TPD program will be discussed in the next section). This study aims to investigate whether the STEM TPD design connects mathematics teachers' knowledge of STEM education to their classroom instruction. correlation research method to achieve this goal. In the discussion section, we will explain why these results are worth considering.

METHOD

The STEM TPD Program

The STEM TPD for in-service mathematics teachers aimed to improve in-service mathematics teachers' STEM knowledge and foster STEM teaching practices in students' classrooms. This program was implemented at a teachers' training center in Yogyakarta, Indonesia. The STEM TPD is carried out using a scheme that combines two phases of classroom instruction (IN-1 and IN-2) and one phase of on-the-job learning (ON) sandwiched between IN-1 and IN-2. Participants in the IN-1 phase are expected to improve their knowledge and understanding of STEM education, including STEM project-based learning (STEM PjBL) (Capraro et al., 2013).

Every session in IN-1 ended with a post-test to assess the teacher's understanding. Meanwhile, during the ON phase, participants practiced teaching STEM to students in their classrooms. The IN-2 phase aimed to encourage teachers to share and reflect on their teaching practices. Table 1 illustrates the STEM TPD program structure.

Table 1. The STEM TPD Program Structure

Phase	Course Material	Duration
IN-1	STEM in the 21st Century S, T, E, M in STEM Education Mathematics Curriculum and STEM Education Teaching Instruction with STEM Project-based Learning (STEM PjBL) STEM Hands-On Practice	Seven days
ON	STEM Teaching Practice	Three months
IN-2	Sharing and Reflection	Three days

Participants

The STEM TPD invited 50 in-service mathematics vocational high school teachers representing all provinces in Indonesia and divided them into two cohorts. Participants are selected based on recommendations from provincial education departments that believe the individual is capable of communicating program outcomes to other teachers for future dissemination. Therefore, this program's random selection of participants cannot be ensured. A total of 12 participants have been teaching mathematics for less than ten years, so participants with more than ten years of experience teaching mathematics as a single subject are pretty dominant. Two teacher educators (TEs) accompanied each cohort; hence, there were four TEs. Of the 50 participants, we only managed to access complete data from 34 teachers (14 male and 20 female). All participants admitted that this was their first time joining the STEM TPD.

Data Collection

The two variables to be correlated are STEM teachers' knowledge and STEM teaching practice. The TEs administered the post-test assessment in each session, and we calculated the average. The maximum post-test score is 100.

Meanwhile, to measure STEM teaching practice, the report on teachers' teaching practices is assessed based on teachers' lesson plans and implementation (see Table 2). The teaching practices score is the average of those four aspects. The maximum score for teaching practices is 100.

The rubric in Table 2 is used to evaluate STEM teaching practice reports. Four TEs validated and provided feedback on this rubric through the focus group discussion.

Table 2. Rubric Scoring of STEM Teaching Practices

INDICATORS	SCORES		
	65-74.5	**75-84.5**	**84.5-100**
Planning (Data Source: lesson plan)	The stages of student activities in STEM-PjBL (reflection, research, application, discovery, and communication) are described in the plan but are not systematic enough to achieve STEM learning objectives.	The stages of student activities in STEM-PjBL (reflection, research, application, discovery, and communication) are illustrated in systematic planning to achieve STEM learning objectives, even though they are not coherent between stages in some parts.	The stages of student activities in STEM-PjBL (reflection, research, application, discovery, and communication) are described in a coherent and systematic plan to achieve STEM learning objectives.
	Lesson plans describe the type of STEM component integration that is not following the project objectives, resulting in some incoherence with student activity plans and assessments.	The lesson plan describes the type of integration of STEM components following the project objectives, yet there is some incoherence with the student activity plan and assessment.	The lesson plan describes the type of integration of STEM components that fits the project objectives and is coherent with student activity plans and assessments.
	STEM projects provide a minimal opportunity for students to apply their vocational skills.	STEM projects enable students to apply their vocational skills, although only during certain phases.	STEM projects allow students to apply their vocational skills at all project stages.
Implementation (Data Source: teaching journal, teacher's report, documentation)	There is evidence that one of the stages of reflection, research, application, discovery, or communication is not functioning properly, and there is evidence that teachers do not reflect on problems and solutions to overcome them in learning and in the future.	There is evidence that all reflection, research, application, discovery, and communication have been successfully implemented, and there is evidence that teachers reflect on problems that arise but do not include solutions to overcome them in learning and in the future.	All stages of reflection, research, application, discovery, and communication were successfully implemented, and the teacher reflected on the problems encountered during implementation and solutions to overcome them in future learning.

Data Analysis

We employed correlation data analysis to understand the relationship between teachers' STEM knowledge and STEM teaching practices. Preliminary data analyses were also conducted to detect the assumptions of linearity and normality for statistical procedures. The two variables that will be correlated are the type ratio and the sample size. We will measure the Spearman correlation index if the assumptions of linearity between STEM teachers' knowledge and STEM teaching practice are met and the Kendal-Tau correlation index if the assumptions are not met (Cleff, 2014). Furthermore, if both variables meet the assumption of normality, then a hypothesis test can be carried out using the null hypothesis, that is, the correlation between STEM teachers' knowledge and STEM teaching practice equals zero. We use a statistically significant rate of 5%.

RESULT

Table 3 shows the descriptive statistics of teachers' STEM knowledge and their teaching practice scores.

Table 1. Statistic Descriptive

Variable	Descriptive	Statistic
STEM knowledge	mean	78.04
	SD	7.98
STEM teaching practice	mean	85.08
	SD	4.80

The assumptions of linearity between STEM teachers' knowledge and STEM teaching practice were met using a scatterplot (Figure 1) and deviation of linearity (Sig 0.671 > 0.05). Figure 1 shows a monotonic relationship between variables. Hence, we used the Spearman coefficient (Spearman ρ) to test the correlation between STEM teachers' knowledge and STEM teaching practice, as both variables are ratios (Fraenkel et al., 2012).

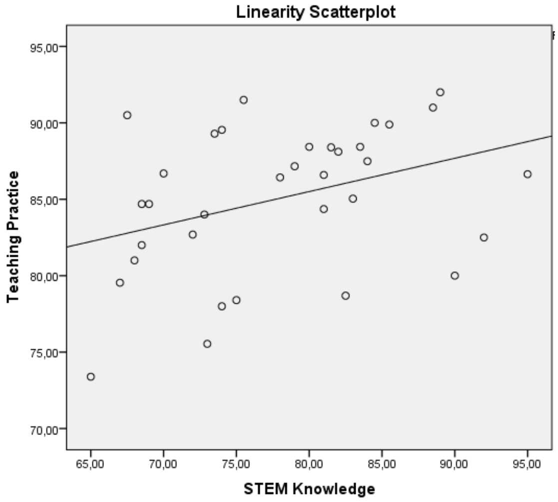

Figure 1. Scatter Plot

The normality test results using Shapiro-Wilk in Table 4 show that the two variables are normally distributed because both Sig values are > 0.05.

Table 2. Normality Test

Variable	Sig	Normality Test
STEM Knowledge	0.329	normal
STEM Teaching Practice	0.108	normal

Because the linearity and normality assumptions are met, the correlation between teachers' STEM knowledge and their teaching practices is determined using Spearman's rho correlation index, and the results are shown in Table 5.

Table 5. Spearman's Rho Correlation Index (SPSS)

			STEM Knowledge	Teaching Practice
Spearman's rho	STEM Knowledge	Correlation Coefficient	1.000	.368
		Sig. (2-tailed)		.032
		N	34	34
	Teaching Pactice	Correlation Coefficient	.368	1.000
		Sig. (2-tailed)	.032	
		N	34	34

Table 5 shows that Sig = 0.032 < 0.05, indicating that the relationship between teachers' STEM knowledge and their teaching practice is significant. It is also clear that the value of ρ = 0.368. We use Fraenkel's (2012) interpretation of the correlation interval, as shown in Table 6.

Table 3. Correlation Interpretation

Magnitudo of *ρ*	Interpretation
0.00 to 0.40	little importance relationship
0.41 to 0.60	large enough relationship
0.61 to 0.80	very important relationship
0.81 or above	very sizable relationship

adapted from Fraenkel (2012) p. 253

Table 5 shows that ρ = 0.368, indicating that ρ is in the interval of little importance relationship. However, Fraenkel et al. (2012) said, "... *unless a random sample was used, interpret probabilities and/or significance levels as crude indices, not as precise values. … report the results of inference techniques as confidence intervals rather than significance levels.*" (p. 253). Hence, using a 95% confidence interval, the result 0.031≤ ρ ≤ 0.672 indicates that ρ stretches from the area of little importance to the area of a large enough relationship.

DISCUSSION

The growing body of research shows that better preparation of mathematics teachers results in better classroom instruction (Ball et al., 2008; Santagata & Lee, 2019). When the in-service teachers participate in a TPD program, they should be facilitated on how their performance in the program relates to their ability to handle the complexity of their profession in the classroom (Gore et al., 2017; Kennedy, 2016). This does not appear to be fully fulfilled by the findings of our study. The fact that the 95% level of the confidence interval is 0.031 ≤ ρ ≤ 0.672 indicates that the correlation between STEM knowledge and STEM teaching practice in the TPD program is in the "little importance relationship" and "large enough relationship" areas.

We propose two perspectives for interpreting this result. First, the possibility that the correlation is large enough to be important suggests that mathematics teachers who have never been exposed to STEM education can benefit significantly from participating in the IN1-ON-IN2 STEM TPD design. This result supports Kennedy's (2016) idea that the STEM TPD somehow combines, in this correlation area, the processes of enhancing teachers' knowledge and assisting them in implementing that knowledge in the classroom. It is implausible for in-service teachers to acquire knowledge in STEM education during their preservice education, particularly for those teachers who have been employed for decades. For this reason, it is essential to provide them with a grounding in STEM knowledge (Han et al., 2015). Furthermore, students will benefit from increased teacher knowledge because of the high correlation, which is what STEM TPD is all about (Jacob et al., 2017; Santagata & Lee, 2019).

It is also worth noting that participants in the STEM TPD program are mathematics teachers who have never previously acquired STEM knowledge. Mathematics in STEM is frequently positioned as the ability to count and calculate, which falls short of mathematics teachers' expectations when taught as a single subject (Marfuah, 2021). Hence, we interpret the large enough importance correlation as evidence that the STEM TPD can assist mathematics teachers in expanding their interdisciplinary STEM knowledge and teaching it to students without neglecting mathematics' great potential. When mathematics teachers participate in the STEM TPD program, the role of mathematics as a powerful tool in problem-solving, reasoning, and modeling is more easily raised in classrooms where mathematics teachers practice STEM education (Sokolowski, 2018).

Second, we will focus on the fact that the ρ also lies in the low-importance correlation area. We will discuss this issue along with some suggestions that accompany improvements to the STEM TPD program in the future. For many points in Fig. 1, teachers' STEM knowledge during the TPD period is not fully proportional to their teaching practice. This result, we suspect, is caused by the transfer of STEM knowledge acquired during STEM TPD to classroom instruction, which is markedly different from the process of transferring single-subject knowledge acquired during a non-STEM TPD (Luft et al., 2020). Transfer of knowledge from STEM TPD to students' classrooms is related to several factors, including communication between participants in STEM TPD, collaboration between STEM subject teachers in schools, the school's environment, the school's support, and teachers' ability to cope with unpredictable cases when conducting their STEM teaching. For example, teachers with lower STEM knowledge scores can have higher teaching practice score, which might be caused by their ability to collaborate with other teachers in their schools on STEM projects. Also, they might have support from the principal.

In contrast, teachers with higher STEM knowledge scores might have difficulty developing STEM projects for students when they do not take the initiative to communicate with their colleagues in STEM TPD, or perhaps, school conditions are not supportive. We also highlight the condition that participants be 100% mathematics teachers, which can be a reason for some teachers' difficulty implementing the interdisciplinary aspects of STEM. Although the STEM TPD brings together STEM experts and science, technology, engineering, and mathematics experts to facilitate teachers' STEM knowledge, the STEM TPD committee needs to consider the cohort model that mixes teachers from various subjects to collaborate on STEM projects.

The incorporation of mathematics and science teachers into a single TPD STEM cohort was demonstrated (Burrows et al., 2021; You et al., 2021) as contributing to the program's effectiveness. By combining the analysis that the participation of mathematics teachers in STEM TPD is thought to be the reason for both strong and weak correlations, we propose that STEM TPD in the future involve mathematics teachers as agents of mathematics knowledge but still place them with teachers from other STEM subjects in one cohort. Thus, we promote the involvement of mathematics teachers in STEM projects while providing access for them to broaden their interdisciplinary knowledge through communication and collaboration within the cohort. We also suspect that the vocational aspect is the reason for school support for teachers for STEM teaching practices. Compared to vocational subjects, mathematics may not be a popular subject for vocational high school students (Kristianti et al., 2022; Marfuah, 2021). Given that the mathematics teachers at STEM TPD work in vocational high schools, we suspect that the alignment of the STEM projects they use in their teaching practices with student vocational majors determines how students motivate and support school infrastructure. Apart from teachers' STEM knowledge, we view that the STEM teaching practices of teachers in vocational high schools have the potential to explore STEM learning resources that already exist in the school environment but are neglected (Marfuah, 2021). Therefore, this study also proposes that STEM TPD for vocational high school mathematics teachers facilitates teachers connections with vocational knowledge in their teaching environment (Dalby & Noyes, 2015; Marfuah, 2021).

We emphasized that one of our study's limitations its the threat to validity. Our work's limitations can be divided into two categories. First, participants were chosen geographically and delegated by their respective educational office districts, ensuring the process was not entirely random. Second, we acknowledge the possibility of inter-rater bias because there were four people (TEs) scoring the STEM knowledge and teaching practices. We do, however, make sure that TEs use a variety of data sources to calculate teaching practice scores. There was no formal protocol for evaluating teaching practices, but an outline of what to assess was agreed upon before the program started. Of course, given the limitations of the study, the findings of this study cannot be generalized. This correlation research, however, remains valuable as a further study for researchers, educators, and other stakeholders involved in the teachers' professional development program.

CONCLUSION

In this study, the STEM TPD with the IN1-ON-IN2 scheme aims to improve the STEM knowledge of in-service mathematics teachers who work in vocational high schools and foster their STEM teaching practices in students' classrooms. This study aims to evaluate the effect of mathematics teachers' STEM knowledge gained in the STEM TPD on their classroom teaching practice. Statistical results show that there is a tendency that the STEM knowledge gained in the STEM TPD is positively correlated with their teaching practice in the classroom, although there are some anomalous points that require further investigation.

We recommend the need for further research to analyze in depth why anomalous points appear in the positive correlation that occurs. We recommend four main ways to improve STEM TPD: transfer of STEM knowledge in the school environment, strengthening interdisciplinary aspects in cohorts, monitoring and mentoring STEM teaching practices, and sustainably strengthening the post-TPD teacher community. Furthermore, a system is needed to assess the quality of teachers' STEM teaching practices in a holistic, valid, and standardized way.

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