JURNAL BIOTERDIDIK: WAHANA EKSPRESI ILMIAH
(*Journal of Bioterdidik: Scientific Expression Media*)

e-ISSN: 2621-5594
p-ISSN: 2302-1276

Vol. 11 No. 2, October 2023, page. 152-161
http://jurnal.fkip.unila.ac.id/index.php/JBT/
doi: 10.23960/jbt.v11.i2.28402

Teachers' Beliefs and Efficacy of Technological Pedagogical Content Knowledge for STEM Learning

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Received: August 6, 2023 *Accepted: Sepetember 1, 2023* *Online Published: October 30, 2023*

Abstract: The application of STEM in Indonesian education has grown. The TPACK framework could enhance teachers' beliefs and efficacy in STEM education. However, there need to be more details evidence of the teacher's beliefs and efficacy when facing or dealing with STEM-based learning. Therefore, exploring the teachers' views and perspectives on implementing TPACK in conducting STEM learning is crucial. This study aimed to reveal teachers' beliefs and efficacy on their TPACK in designing STEM learning. The case study method was used with 9 participants enrolled in a STEM learning program for science teachers. Teachers' self-assessment questionnaires and online interviews collected teachers' TPACK beliefs and efficacy. We analyzed quantitative data from self-assessment questionnaires using interval class analysis. We used a descriptive approach to analyze data from interviews. The results show that teachers regard themselves as highly competent in implementing their TPACK on STEM learning. Out of the three TPACK domains, teachers showed better efficacy in the integrative STEM domain. Of the three TPACK domains, teachers showed better efficacy in the integrative STEM domain than in technology-related knowledge. They are, nevertheless, generally enthusiastic about improving their technological skills. These findings reflect the urgent need to provide professional teachers programs to support this positive belief and efficacy on teachers' TPACK for STEM learning.

***Keywords*:** *TPACK, STEM, Efficacy, Belief, Teacher Perspective*

INTRODUCTION

Science, technology, engineering, and math, referred to as STEM, is an interdisciplinary subject of study believed to meet the challenges of the 21st century(Ng, 2019). The primary goal of STEM application in education is to prepare students for dealing with daily or social issues, making learning more relevant and practical. STEM education involves teachers and students in active, purposeful learning, which is essential and impactful for developing young learners(Thomas & Larwin, 2023).

STEM education has been receiving an extensive amount of attention in recent years (Mildenhall et al., 2019). Although the application of STEM in Indonesian education has grown(Nugroho et al., 2019), students still need to improve in many ways, especially in knowledge construction when they engage in STEM-based learning (Muthmainnah et al., 2023). So, there is a greater need for teachers capable of effectively conducting STEM learning.

Teaching STEM-related content to students in the classroom involves both opportunities and challenges. One of the many challenges for applying STEM learning lies in addressing content and pedagogy(Dare et al., 2019). Teachers must utilize their content knowledge for suitable learning activities and engage students to learn, often known as pedagogical content expertise (PCK)(Shulman, 1986). In the context of STEM, which integrates various disciplines (Bybee, 2010), including technology, it is not enough for teachers to master PCK. Teachers must integrate technology into learning (König et al., 2020) including STEM learning. Technology pedagogical content knowledge (TPACK) is the term for this type of knowledge. TPACK has proven to be a practical framework for conveying the skills and knowledge teachers need to design lessons for the digital age classrooms(Koehler et al., 2013).

The TPACK framework proposed by Mishra and Koehler is a development of PCK (2006). This framework emphasizes the requirement for a teacher to truly comprehend the subject matter (content knowledge), choose appropriate instruction (pedagogical knowledge), use suitable technology (technological knowledge), and how integrate all three of these elements in learning (Koseoglu, 2012). Teachers who use the TPACK framework can assess their needs in order to improve their capacity to plan teaching and learning activities (Rochintaniawati et al., 2019). This framework is critical, considering that teachers' TPACK limitations affect the quality of learning (Neuman & Danielson, 2021), including implementing STEM-based learning.

According to current research, the growth of TPACK research has yet to transform the situation of technology integration in classrooms (Voogt et al., 2013). One piece of empirical evidence from previous research states that teachers' TPACK levels are still recognizing, accepting and adapting. The teachers' TPACK level of teachers has yet to move to exploration and advance (Muthmainnah & Nurkamilah, 2021). One of the things that affect teachers' TPACK is belief and efficacy(Corry & Stella, 2018).

According to Bandura, teachers' efficacy refers to teacher views about their capacities to succeed in various teaching and learning settings(Flammer, 2015). Nonetheless, teachers' beliefs and efficacy can also be an enormous barrier to teaching and learning(Ertmer, P., Anne, O.-L., & Tondeur, 2015). These studies suggest that self-efficacy is critical for teachers included in teaching and learning in unfamiliar conditions(Lauermann & König, 2016). However, there is limited details evidence of the teacher's beliefs and efficacy when facing or dealing with the implementation of STEM-based learning.

Furthermore, teachers' beliefs have been identified as a domain that requires research on teachers' TPACK, as these constructs have an inherent role in impacting teachers' instructional decision-making(Tondeur et al., 2017). Therefore, exploring the teachers' beliefs and efficacy of their TPACK in conducting STEM learning is crucial. Initially, one broad question that guided our study was how teachers' beliefs and TPACK-efficacy in designing STEM learning. This study attempts to reveal teachers' views and perspectives on implementing TPACK in STEM learning.

METHOD

Research Design

In order to explore teacher beliefs and efficacy regarding using TPACK for planning STEM learning, this study used a single case study design(Yin, 2009). The case study approach reveals how views and intangible ideas can coexist in real-life situations. First, we distributed questionnaires through training exercises as part of the study. The test results were then descriptively analyzed. Based on the result, we interviewed to obtain more profound information about teachers' TPACK efficacy and belief.

Population and Sample

This study was conducted online on July 7 and 13, 2023, through the Zoom meeting and google forms application during STEM training activities. A total of 9 science teachers from Garut City who enroll for STEM training program participated in this study. Participants are also members of a science teacher association in Garut City. The main criteria for teachers as participants in this study are that all teachers are unfamiliar with and have never designed and implemented STEM-based learning. The participant voluntarily joined the research and provided informed consent per protocols approved by university. Table 1 displays demographic information on teachers.

Table 1. Participants Demography

Demographics Variable	**N**	**%**
Female	9	100
Teaching Experience		
< 1 year	2	22.2
1 - 5 years	6	66.7
> 5 years	1	11.1
School Status		
Public	2	22.2
Private	7	77.8

Research Instrument

Teachers' self-assessment questionnaires and online interviews collected teachers' TPACK beliefs and efficacy. The self-assessment questionnaire was modified based on prior studies(Chai, Jong, et al., 2019). The questionnaire assessed three dimensions: teachers' belief in STEM-based learning, teachers' belief in integrative STEM, and teacher TPACK-STEM efficacy. Meanwhile, TPACK-STEM efficacy covers three domains which are technological pedagogical science knowledge (TPSK), technological pedagogical mathematics knowledge (TPMK), and technological pedagogical engineering knowledge (TPEK).

The questionnaire comprised 16 statements asking teachers to rate their TPACK beliefs and efficacy. Three open-ended questions were included to explore teacher perceptions of integrating technology in STEM learning in terms of challenges, advantages, and limitations. Two experts validated the instrument, and then a readability test was conducted. Table 2 offers an example of a questionnaire statement.

Table 2. Example of Questionnaire Statements

Dimentions	N	Statement
Teachers' Belief	6	I am confident in designing decent STEM learning.
		I am confident in handling difficulties while conducting STEM learning.
iSTEM	6	I can find real-life problems that could stimulate student learning through STEM.
		I can design proper learning activities to integrate STEM elements.
TPACK-STEM Efficacy	6	I can integrate technology that can be used in STEM learning.
		I am competent in helping students to analyze the science element of STEM learning.

Furthermore, we interviewed two teachers to obtain more in-depth information about the state of teachers' TPACK beliefs and efficacy. Based on their answers to the questionnaire, these two teachers have chosen to represent two typical patterns of teachers' TPACK belief and efficacy in STEM learning. Their responses could describe more about the current state of science teacher views and efficacy.

We analyzed the data obtained from the instrument in two stages. First, we analyzed quantitative data from five-level Likert scale questionnaires using interval class analysis(Nuryadi et al., 2017). Then we used a descriptive approach to analyze data from interviews(Loeb et al., 2017). Through analysis of data, we defined a phenomenon and discovered patterns in data to address the primary research questions on how science teachers' TPACK belief and efficacy in designing STEM-based learning.

RESULT AND DISCUSSION

Result of Research Procedure

Evidence of teacher TPACK belief and efficacy is difficult to obtain, primarily related to inferential statistical analysis. The issue is that a larger sample size of teachers is required. As a result, this study has descriptive statistics for analyzing teachers' self-assessment questionnaires on their TPACK beliefs and efficacy. Table 3 shows the science teachers' TPACK belief and efficacy in planning STEM learning. Overall, the descriptive analysis shows that teachers are in a high category. Out of the three dimensions, integrative STEM (iSTEM) is the only one in a "very high" category. Meanwhile, the rest are in a "high" category. The result shows that teachers regard themselves as highly competent in implementing their TPACK on STEM learning.

Table 3. Teachers' Beliefs and Efficacy Score on their TPACK For STEM Learning

Dimensions	Score	Category
Teachers' Belief		High
iSTEM		Very high
TPACK-STEM Efficacy		High

This outcome indicates that teachers are confident in applying STEM learning and implementing TPACK properly. This vies was backed by the fact that 88% of participants were recently graduated and eager to learn and adopt something new and challenging, such as STEM-based learning. Other research suggests that teaching experience contributes to learning effectiveness(Podolsky et al., 2019).

Table 4 shows specific details data for the TPACK-STEM dimension: technological pedagogical science knowledge (TPSK), technological pedagogical mathematics knowledge (TPMK), and technological pedagogical engineering knowledge (TPEK). The descriptive analysis shows that teachers are all in a high category. This outcome indicates that teachers are confident in integrating technology in STEM learning, whether on science, engineering, or mathematics-related element. This result indicates a positive attitude toward technology integration in STEM learning, as a previous study state that it is crucial for teachers to have strong confidence related to STEM teacher development(Margot & Kettler, 2019).

Table 4. Teachers' Efficacy Score on their TPSK, TPEK, and TPMK For STEM Learning

Dimensions	Score	Category
TPSK		High
TPEK		High
TPMK		High

Additionally, we coded an answer to open-ended questions and interview transcript to identify evidence of teachers' perception of general versus STEM-related specific uses of technology. Figure 1 provides data for each of the codes. This result indicates that teachers' mostly perceived using technology as part of general learning, such as formative assessment, learning media and student worksheets. Meanwhile, teachers perceived the use of less technology for STEM-related activities in learning. This evidence aligns with other studies that state teacher confidence in using technology, in general, is more significant than in content-specific learning(Charles R. Graham et al., 2009).

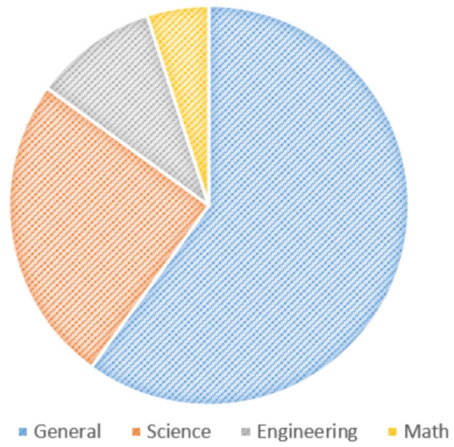

Figure 1. Teachers' Perception on Specific Uses of Technology in STEM Learning

Discussion

This study aimed to reveal teachers' beliefs and efficacy on their TPACK in designing STEM learning. The following discussion is about the result and the implications of this study. The results show that teachers regard themselves as highly competent in implementing their TPACK on STEM learning. It is consistent among three TPACK beliefs and efficacy dimensions.

This study's findings about the high teachers' TPACK efficacy and belief are comparable to those of earlier research done in the context of STEM-based learning. A researcher in Hongkong assesses teachers' Self-efficacy and Concerns about STEM Education(Geng et al., 2019). Meanwhile, a Chinese researcher modeling teacher design beliefs and TPACK efficacy in the context of modern learning (Chai, Hwee Ling Koh, et al., 2019). However, this study explores teachers' beliefs and efficacy in the context of STEM-based learning for teachers unfamiliar with it.

The outcome from previous studies and our study have in common that beliefs and efficacy are significant predictors of the teachers' knowledge of how to design or conduct suitable learning activities for students. According to a similar study on this topic, understanding teachers' TPACK self-efficacy may be a helpful approach to figuring out teachers' readiness for teaching and learning activities(Muthmainnah & Nurkamilah, 2022).

This study's findings strengthen our understanding of how beliefs and efficacy contribute to the growth of teachers' TPACK, particularly when teachers encounter challenging learning activities including STEM. Previous research in Germany has identified teacher efficacy as a key educational resource (König et al., 2020). This finding could serve as a basis for constructing a professional development programme to enhance teachers' TPACK.

The current study has at least two limitations. First, the study's small sample size yet was sufficient. In regard to this, it could be necessary for the following research to expand the participant number. Second, for the iSTEM dimension, the instruments are too general or lack detail of various disciplines in STEM. This aligns with another study that said for teachers to be effective in teaching STEM-related topics, they must go beyond just being experts in a discipline matter of technology and become fluent in another discipline as well(Chai, Hwee Ling Koh, et al., 2019). Future studies should consider ways to measure teacher multi-disciplines fluency and explore how it relates to their TPACK STEM.

CONCLUSION

This study aimed to reveal teachers' beliefs and efficacy on their TPACK in designing STEM learning. The results show that teachers regard themselves as highly competent in implementing their TPACK on STEM learning. This study's findings strengthen our understanding of how beliefs and efficacy contribute to the growth of teachers' TPACK, particularly when teachers encounter challenging learning activities including STEM. However, despite high teachers' TPACK beliefs and efficacy, there needs to be more evidence of teachers' TPACK beliefs and efficacy in action. Therefore, future studies should consider ways to explore how teachers apply it in the actual classroom.

GRATITUDE

We are grateful to Direktorat Jenderal Pendidikan Tinggi, Riset, dan Teknologi for supporting our research financially.

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