A systematic literature review of science teachers’ TPACK related to STEM in developing a TPACK-STEM scale

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Abstract. The success of implementing STEM in learning activities must begin with increasing the teachers’ TPACK ability. However, information about TPACK and STEM is currently limited. Thus, this article aims to analyze articles related to TPACK and STEM and start the development of TPACK-STEM instruments. This study is a systematic literature review that conducted based on the PRISMA statement. Based on the search results, 21 search results were obtained. The results consist of 16 articles and 5 chapters. The analysis shows that the application of TPACK-STEM requires a complex process. There are three stages in implementing TPACK-STEM. First, the development of TPACK instrument. Second, the process of developing teachers' TPACK-STEM ability. Third, the application of TPACK-based STEM learning to students. This information is the first step in developing the TPACK-STEM instrument.

1. Introduction
Science, Technology, Engineering, and Mathematics (STEM) education is the foundation for economic growth and receives continuous attention from the ministry of education \cite{1}. Through STEM education, students have the opportunity to become problem solvers, innovators, creators and collaborators that are very important for the nation's future \cite{2}. However, interest in STEM fields in developed countries such as the USA, UK, Europe, and Australia has dropped dramatically \cite{3}\cite{4}. As with Indonesia, the growth of STEM-based education in this country has not been well developed. The research results showed that most of the study respondents did not have sufficient knowledge or had never even heard about STEM-based education \cite{5}. These two issues led to the same solution, the need to improve STEM-based education in schools.

Teachers have an important role in providing STEM education and knowledge that is appropriate for their students. Furthermore, the teachers play an important role in helping students to determine their future careers based on their STEM \cite{1}. Therefore, to optimize the application of STEM, the teacher needs to be given special attention, especially regarding how they carry out teaching and learning activities that are in line with the current development, namely teaching and learning by
integrating technology [6]. Teachers should have the ability to carry out learning activities using technology appropriate to the content and pedagogy.

The ability of teachers to choose and use technology that appropriates with content and pedagogy can be seen through the TPACK framework [7]. The use of the TPACK framework in supporting teachers to improve their professionalism is a perfect choice, especially in Indonesia. Three main reasons are underlying this claim. First, the TPACK framework can be used to understand, identify, and provide an overview of the teacher's ability to implement effective technology-based learning [6,8]. Second, the TPACK framework is suitable for the competence of Indonesian teachers [7,9,10]. Third, the technology that referred in TPACK is not limited to digital technology. The TPACK Framework emphasizes the selection of technologies that are appropriate to the context and pedagogy [8]. Therefore, teachers can adjust the technology to be used based on the needs and availability of technology in their schools.

The success of implementing STEM in learning activities must begin with increasing the ability of teachers to carry out learning activities, especially technology-based learning. To improve the ability of teachers to carry out learning, it can be done by analyzing their TPACK abilities. It aims to obtain initial information about the state of the teacher. Furthermore, assistance and support are given based on these findings. However, information about TPACK and STEM is currently limited. Thus, this article aims to analyze articles related to TPACK and STEM and start the development of TPACK-STEM instruments. This article is useful to get an initial portrait of research on TPACK and STEM.

2. Method

2.1. Research Strategy
This study is a systematic literature review conducted based on the PRISMA statement [11]. Analysis and discussion based on the following questions.
RQ1: How to develop TPACK and STEM for teachers and students?
RQ2: How to measure TPACK related to STEM science teachers?

2.2. Identification of Source
The review is limited to articles published in the period of 2015-2019 in the education discipline. It aims to obtain comprehensive information and the latest trends regarding research on TPACK and STEM for science teachers. The keyword search is related to the research objectives. Furthermore, each search continues with the keyword and Boolean operators as follows.

(Science) AND (teacher or teachers) AND (TPACK) AND (related) AND (STEM)

Based on the search results, there are 122 records identified through Springerlink and 180 records identified through the Perpusnas web search.

2.3. Eligibility Criteria
Based on research purposes, we only analyzed articles that related to the development of TPACK and STEM. Furthermore, the articles selected are articles that use quantitative, qualitative research designs, or mix methods. Samples of the research are also our concern. The sample must consist of a teacher, student, or both. After searching and extracting data, a synthesis of 8 articles was carried out (Figure 1).
Results and Discussion

The search results and data extraction produced 8 articles that match the criteria to answer research questions (Figure 1). Articles selected for analysis in this review show in Table 1.

Table 1. The selected studies on TPACK and STEM (n = 6)

| Study                          | Subjects          | Method                                      | Data sources                              |
|-------------------------------|-------------------|---------------------------------------------|-------------------------------------------|
| Kaplon-Schilis & Lyublinskaya | Pre-service teachers | Long-term single study                      | Multiple-choice questions, short and extended response items, constructed response questions, and the TPACK levels rubric. |
| Meletiou-Mavrotheris & Prodromou | Pre-service teachers | A case study design with mixed methods      | Electronic open-ended pre-survey, individual open-ended interviews, classroom observations and artifacts, and field notes and reflection papers that prepared by participants |
| Ng & Fergusson                | Teachers          | Interpretive, critical, theoretical framework within a mixed methods | Transcriptions of audio-recorded focus group interviews, extensive researcher field notes, classroom observations and conversations, post-project online survey and open-ended questions. |
3.1. Development of TPACK and STEM for teachers and students

The results of the analysis showed three groups of data that can be used as stages of development of teachers’ TPACK and students' STEM abilities. In general, this stage consists of the development of a TPACK instrument [12], the process of developing teachers’ TPACK and STEM capabilities [3][13][14], and the application of TPACK-based STEM learning to students [15][16]. Furthermore, to obtain optimal results, the research results suggest that the need for collaboration between science teachers, researchers, educational technology service providers in creating a technology-based educational product. The results of these studies state that the product of collaboration has a positive effect on teachers and students [3].

3.1.1. Development of TPACK Instruments

The development of instruments is an important stage in the development of TPACK-STEM. The researcher must recognize what subjects and indicators are needed by the teacher and students. In the end, the instruments can be used as reference material in helping teachers develop their TPACK-STEM.

Table 1 shows that the instruments used to measure the development process of teachers' TPACK consist of various types. According to research results [12], TPACK measurements conducted in two ways, self-assessment and external assessment. Self-assessment consists of self-report, questionnaire, multiple-choice questions, short and extended response items, constructed response questions, field notes and reflection papers. Furthermore, the external assessment consists of interviews, classroom observations, and artifacts or something judged by others.

The use of instruments is determined by two factors, the research subjects, and aspects to be measured. According to research results [14], an instrument which is used for the in-service teacher is not suitable for the pre-service teacher. This is due to pre-service teachers do not have teaching experience such as in-service teachers. Furthermore, the use of instruments is also determined by the aspects to be measured. The results of the analysis show that to measure a piece of knowledge, instruments are used in the form of tests, such as Technological Knowledge Test (TKT), Pedagogical
Knowledge Test (PKT), Content Knowledge in Mathematics Test (CKMT), Content Knowledge in Science Test (CKST) [12]. Whereas to measure perceptions can use questionnaires.

Instrument TPACK can also be developed based on each TPACK component independently. Research results [12] showed that the components of TPACK, TK, PK, CKM, CKS can be measured separately using the instruments they have developed. This is in accordance with Mishra & Koehler [19] which states that each TPACK component must be considered a different construct.

3.1.2. The process of developing the teachers’ TPACK and STEM ability
Table 1 shows that the method used to improve teachers’ TPACK and STEM ability is almost mixed. The data source used is also multi-form, consisting of quantitative and qualitative data. It shows that to improve the ability of TPACK and STEM, teachers need a long process and cannot be assessed from one data source.

The application of TPACK-based STEM must begin by identifying the ability of teachers in implementing good learning. These capabilities can be identified using the TPACK framework [18]. To obtain more specific results, in this case, STEM-based learning, it is necessary to adjust the TPACK instrument. For example, incorporating STEM-based learning indicators into TPACK indicators and constructs.

According to Quigley & Herro [17], STEAM-based learning (science, technology, engineering, arts, and mathematics) is influenced by the relevance of the material, student choices, the type of technological integration, problem-based learning, and the use of authentic assessments. These results provide a piece of information that STEAM-based learning is student-centered learning and affected by student characteristics. Therefore, teachers are expected to be able to properly identify the characteristics of their students.

3.1.3. Application of TPACK-based STEM learning
The application of TPACK-based STEM learning in this review refers to research by Novak & Wisdom [14], Miller [15], and Strawhacker et al. [16]. The three results of this study can provide a complete picture of the application of TPACK-based STEM learning. This is because the research subjects consisted of three different groups, pre-service teachers [14], students [15], and teachers with students [16].

The difference in research subjects also determines the complexity of the learning process. Research from Novak & Wisdom [14] using a combination of software and hardware and analysis. Meanwhile, research from Miller [15] and Strawhacker et al. [16] focused on software. Both researches focus on mobile applications. This is in accordance with the subject of their research, kindergarten students.

The learning model used for the application of learning is also different. Research from Novak & Wisdom [14] used 5E Learning Cycle for inquiry science teaching. There are five phases to this instructional model: Engagement, Exploration, Explanation, Elaboration, and Evaluation [14]. Research from Miller [15], and Strawhacker et al. [16] apply game-based learning using mobile devices. An interesting result of mobile device-based learning is that data sources can be obtained using screen casting. Through screen casting, researchers can obtain data in the form of video, audio, and response patterns given by research subjects [16].

3.2. Measuring science teachers TPACK related to STEM
Determining how to measure the ability of TPACK-STEM science teachers is still a challenge for teachers and researchers. This is caused by the ability of TPACK-STEM is an internal ability of teachers that can only be actualized by the teacher if the teacher has certain knowledge and experience. Therefore, to obtain an overview of the teacher's TPACK-STEM capabilities, several types of instruments are needed to assess it [12].

Measurement of TPACK-STEM science teachers can be grouped into two, namely type of data and the subject of the assessor. Based on the type of data, it consists of quantitative data such as survey
results and qualitative results such as interviews. Furthermore, the ability of TPACK-STEM can be obtained by personal or by others (external). Personal measurements using self-assessments such as questionnaires and external measurements using assessment rubrics, artifacts, and interviews [12].

3.3. Further development for TPACK-STEM for science teachers

Based on the results of the analysis, there is important information obtained in the development of the TPACK-STEM instrument. The development of TPACK-STEM instruments should focus on long-term interests. TPACK-STEM instruments can be developed based on TPACK-forming constructs. This aims to help the identification of teacher abilities. So that researchers and the government can help improve teacher professionalism.

4. Conclusions

The analysis shows that the application of TPACK-STEM requires a complex process. There are three stages in implementing TPACK-STEM. First, the development of TPACK instrument. Second, the process of developing the teachers’ TPACK-STEM ability. Third, the application of TPACK-based STEM learning to students. This information is the first step in developing the TPACK-STEM instrument.

5. References

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