Instruments for Measuring Pre-service Mathematics Teachers' TPACK Skill in Integrating Technology: A Systematic Literature Review

Naufal Ishartono, Siti Hajar binti Halili*, and Rafiza binti Abdul Razak

***Abstract*—A Systematic Literature Review (SLR) was undertaken by many researchers to examine studies that examined Pre-Service Mathematics Teachers' technology integration skills in the Technological Pedagogical Content Knowledge (TPACK) framework. However, there has been little SLR research that analyzes the tools employed by earlier studies to measure these skills. As a result, this SLR investigates the instruments used to assess Pre-Service Mathematics Teachers' (PSMTs) TPACK skills in integrating technology during teaching practice by addressing three issues: 1) what instruments have previous studies used to assess PSMTs' TPACK skills in integrating technology? 2) what instruments are frequently used as references? and 3) what other frameworks are combined with TPACK in the measurement? This study adhered to the PRISMA guidelines based on the Scopus and Web of Science databases. This study filtered out 17 papers in total. According to the findings of this study, the TPACK questionnaire is the most commonly utilized instrument by researchers in the examined studies. The best appropriate instrument is the TPACK questionnaire created by Schmidt *et al*. Finally, attitude and perception are heavily incorporated into studies testing the TPACK skills of PSMTs. Future studies can use this study to determine the best instrument for testing PSMTs' TPACK skills.**

***Index Terms*—Technological Pedagogical Content Knowledge (TPACK), pre-service mathematics teachers, technology integration**

I. Introduction

Many previous studies aimed to improve students' understanding of mathematical concepts by integrating digital technology in mathematics learning, such as GeoGebra, Matlab, android applications, Augmented Reality, and Virtual Reality [1–5]. Integrating digital technology in mathematics learning helps teachers deliver relatively complex mathematical concepts more efficiently [6]. The complexity of mathematical concepts arises from mathematical objects which have an abstract nature [7]. Therefore, teachers' awareness of the need for digital learning media to bridge teachers' delivery and students' understanding of mathematical concepts is fundamental. Realizing the importance of digital technology integration in mathematics learning, the skills of teachers must be prepared as early as possible, especially at the Pre-Service Mathematics Teachers (PSMTs) level.

By definition, PSMTs are similar to other college students. PSMTs are Pre-Service Teachers (PSTs) that study mathematics education under the program of the mathematics education department in educational faculty or at higher education institutions [8]. PSMTs also get a curriculum and programs to become prospective professional mathematics teachers like pre-service teachers. Some examples of programs provided to PSMTs are microteaching and school-teaching internships. Microteaching is a course that focuses on developing the initial skills of PSMTs in teaching [9]. In this course, they practice teaching their peers who pretend to be students. Of course, these activities are under the supervision and evaluation of lecturers regarding teaching techniques, the validity of the materials taught, and their skills in delivering the materials. This course is a prerequisite to continue to the school-teaching internship program, where the PSMTs become assistants for in-service teachers in teaching and managing classes. The main goal of a teaching internship is to strengthen and deepen the knowledge gained by students in the learning process and to improve their skills and knowledge of the future profession [10].

Almost all universities that organize the Professional Teacher Training Program (PTTP) in Indonesia provide microteaching and school-teaching internship programs as part of their curriculum [11]. The same programs also run in China, Korea, and Turkey, where universities in the three countries provide microteaching and teaching internship programs for PSTs [12–14]. This is done to ensure that the PSTs have enough experience and initial insight as professional teacher candidates. Many pedagogical concepts are taught in these programs, one of which is the improvement of PSTs' skills in integrating digital technology into their teaching practice.

The digital technology integration skills given to them are about using digital-based mathematics multimedia—Such as GeoGebra, MATLAB, Statistical Package for Social Sciences (SPSS), and Desmos—as part of various mathematics teachings activities such as assessment, information delivery, visualization of mathematical objects, and simulation of mathematics concepts. Therefore, a framework is needed to assist PSMTs in integrating technology into their teaching practice.

A. Theoretical Perspective of Technology Integration in Mathematics Education

Technological integration in education has become a long-standing issue among educational researchers.

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Researchers in the field of education have highlighted the importance of improving the quality of the learning process in terms of effectiveness and efficiency without reducing the meaningfulness of the learning process. In the mathematics learning process, the technology integration helps mathematics teachers in many aspects, where one of which is in terms of material visualization [1]. Although experts have no agreement regarding the definition of mathematics, some argue that mathematics has abstract working objects [15–18]. Since the processing of abstract objects only occurs in the brain, it can be said that mathematics is a cognitive activity [19]. The problem is that not all students have good mathematical abstraction skills. So, a medium that makes abstract mathematical objects easier for students to understand is needed [20]. In that case, technological integration becomes significant, namely, visualizing abstract mathematical objects.

Previous researchers have developed frameworks that guide teachers in integrating technology into their learning designs (see Table I for the sample of technological integration frameworks). Table I shows several technological integration frameworks often used by researchers in education: Technological-Pedagogical-Content-Knowledge (TPACK); Substitution, Augmentation, Modification and Redefinition (SAMR); Universal Design for Learning (UDL); Technological Integration Matrix (TIM); Technology Integration Planning (TIP); Level of Technology Implementation (LoTi); Passive, Interactive, Creative Replacement, Amplification, and Transformation (PIC-RAT); and Translational, Transformational, and Transcendent (T3). Table I also shows the number of research publications (n) related to each framework where the data were taken from the ERIC (Education Resources Information Center) database. The selection of ERIC is based on the reason of the article selection on ERIC is relatively high [21]. The data collection was carried out with the limitation that the articles were research articles published between 2018 and 2022. Based on Table I, this section compares the three frameworks with the highest number of research articles: TPACK, Universal Design for Learning (UDL), and SAMR.

TABLE I: TECHNOLOGICAL INTEGRATIONS FRAMEWORKS

Frameworks	Inventors	Description	n
TPACK	[22]	This framework combines three main knowledge components, namely technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK).	413
SAMR	[23]	This framework consists of substitution (S), augmentation (A), modification (M), and redefinition (R).	43
UDL	[24]	The Universal Design for Learning (UDL) framework consists of three principles which are multiple means of representation (MMR), multiple means of action and expression (MMAE), and multiple means of engagement (MME).	239
T3	[25]	The T3 framework consists of three hierarchical domains: T1) Translational, T2) Transformational, and T3) Transcendent.	1
TIM	[26]	TIM (Technological Integration Matrix) has five interdependent characteristics of meaningful learning environments: active, collaborative, constructive, authentic, and goal-directed.	0
PIC-RAT	[27]	PICRAT consists of two parts which are PIC (passive, interactive, and creative) and RAT (replacement, amplification, and transformation)	1
TIP	[28]	TIP (Technology Integration Planning) is a framework that has seven steps, namely 1) identifying an instructional goal, 2) determining a pedagogical approach, 3) considering tools, 4) contributing to instruction, 5) identifying constrain, 6) delivering instruction, and 7) reflecting.	3
LoTI	[29]	LoTI (Level of Technology Implementation) has six levels, namely level 0 (non-use), level 1 (awareness), level 2 (exploration), level 3 (infusion), level 4a (mechanical integration), level 4b (routine integration), level 5 (expansion), and level 6 (refinement).	4

The TPACK Framework or Technological, Pedagogical, and Content Knowledge is a framework proposed by Puentedura [23]. In addition to having three essential components—TK, PK, and CK—the combination of the three components also produces three combined components, namely TPK (Technological and Pedagogical Knowledge), TCK (Technological and Content Knowledge), and PCK (Pedagogical and Content Knowledge). This framework has been widely used by previous researchers who examine how teachers integrate technology in education from practical and psychological aspects, such as related to teachers' beliefs on technological integration using TPACK [30–34].

The second framework is Substitution, Augmentation, Modification, and Redefinition (SAMR) which was first introduced by Puentedura [23]. This framework is a development of the framework RAT (Replacement, Amplification, and Transformation) proposed by Hughes and Thomas *et al.* [35]. This framework encourages educators to improve the quality of learning via technology. However, this framework is considered unclear regarding boundaries level, specifically between augmentation and substitution [27]. In addition, Kimmons argues that this framework's level of distinction may not be meaningful for practitioners.

Lastly, Universal Design for Learning (UDL) Framework is a framework initiated by the Center for Applied Special Technology (CAST) in 2012; this framework is an approach to instruction that promotes access, participation, and progress in the general education curriculum for all learners [24]. UDL acknowledges the necessity to provide curricula and instructional activities that allow for multiple forms of representation, expression, and interaction to promote the inclusion of diverse learners [36]. Based on this explanation, it can be said that this framework is not explicitly made for integrating technology into the learning process.

In teaching mathematics in the 21st century, teachers' skills in integrating digital technology into learning are one of the factors that can determine the success of the transfer of knowledge [37]. Mathematics that contains abstract objects requires the teachers to be able to make the object closer to students' life. The more students can feel it through their senses, the more meaningful the learning process will be, for example, when the teacher visualizes abstract objects or lets students manipulate the digital mathematics learning media. Therefore, the technological integration framework is an essential framework that mathematics educators must hold. The framework in question can relate to the teachers' basic knowledge of technological aspects, pedagogical aspects, and aspects of the material taught. Thus, the technological integration framework that complies with these demands is TPACK.

B. TPACK and Pre-service Mathematics Teachers

The need for a theory and framework for the concept of professionalism of a teacher prompted Shulman to propose a framework called PCK, or Pedagogical and Content Knowledge [38]. The PCK framework proposed by Shulman includes a dynamic and complex relationship between pedagogical knowledge and content knowledge (the material taught) (See Fig. 1). According to Shulman, PCK integrates content knowledge and pedagogy and affirms teachers' understanding of how a topic is structured, adapted, and presented according to the diversity of students' abilities and interests [38]. Furthermore, Shulman suggested that subjects' pedagogy and content should be integrated because teaching pedagogy and content as separate activities was not adequate. PCK became a fundamental framework for researchers and practitioners in the field of education and became the basis for the subsequent extensive educational research [39].

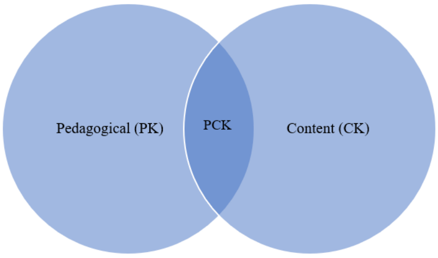

Fig. 1. Pedagogical content knowledge.

Studies related to the PCK framework continue to develop and adapt to the times. One of the adjustments made is the one by Mishra and Koehler [22], where they integrated technological knowledge into the PCK framework and became TPCK (Technology, Pedagogical, and Content Knowledge). This is because, in 2006, computer technology significantly developed fast and entered education. Moreover, Mishra and Koehler [22] also argues that teaching using technology is very complex for teachers. They saw that existing technology was still partial and did not support each other, such as pencils used for writing and microscopes used only to see small objects. Therefore, integrating technology in PCK becomes an escape from educational problems required to be effective and efficient; students can fully understand the material taught using various resources that can increase their understanding. Until 2008, some research communities proposed a more pronounced name, TPACK [40]. To date, the TPACK framework has become a reference for assessing teachers' skills in teaching, focused on how teachers can connect their pedagogical knowledge, content knowledge, and technological knowledge in a comprehensive and meaningful learning process [41, 42].

The TPACK framework in Fig. 2 explains the knowledge of technology (TK), the knowledge of content (CK), and the knowledge of pedagogical (PK). TK in this framework is the knowledge related to how a teacher knows and understands how to operate technologies such as specific tools, software, and hardware and integrate them into a learning process. With this technology, learning becomes more meaningful and comprehensive. Next, CK is teachers' knowledge of the content they teach. The knowledge related to the material taught must be valid so that what is delivered to students is also valid. The last is PK, which is knowledge of learning approaches, models, and strategies and their syntax. In addition, this knowledge is also related to various learning administrations that can help improve the quality of learning.

Apart from the three main components, Fig. 2 also comprises a combination of the two components, such as the combination of the knowledge of content and technology (TCK), the knowledge of technology and pedagogy (TPK), and the knowledge of pedagogy and content (TPC). TCK is teachers' knowledge of integrating technology in the content taught, such as in mathematics and how to visualize mathematical objects using computer software. Next, TPK is teachers' knowledge of integrating technology into their pedagogical knowledge, such as utilizing PowerPoint in the active learning-based learning process. The last is TPC, teachers' knowledge of good teaching of the materials based on a particular learning approach, model, or strategy.

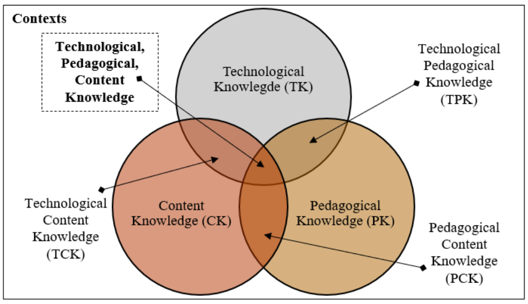

Fig. 2. The TPACK framework.

From the three combinations, Koehler united them into a technological-pedagogical-content knowledge (TPACK) framework [43]. More importantly, the framework is the complex context on which the teachers' actions rely [44]. Schmidt and Baran *et al.* [45] define TPACK as a helpful framework for thinking about what knowledge teachers must have to integrate TPACK as a framework for measuring teaching knowledge which could potentially impact the type of training and professional development experiences designed for both pre-service and in-service teachers. The same notion is also conveyed by Niess [46] under TPACK, which is principally an integration of knowledge of the subject matter, technology, and teaching-learning. TPACK requires an understanding of the conceptions of using technologies such as (1) pedagogical techniques that use technology in constructive ways to teach content, (2) knowledge of how to make initially tricky concepts more accessible for students to understand, (3) knowledge of students' prior knowledge and theories epistemology, and (4) knowledge of how technology can be used to build existing knowledge and evolve it into a new epistemology or strengthen the old epistemology [47]. Based on this definition, TPACK teachers can combine three elements (pedagogical knowledge, content knowledge, and technological knowledge) into learning to simplify the complexity of a concept so that it is easy for students to understand. The teachers can establish effective solutions, pointing to an adaptable, pragmatic, in-depth, and comprehensive understanding of instructional activities with technology [43].

In mathematics education, the TPACK framework has been widely studied concerning how pre-service teachers can integrate technology to deliver mathematical concepts in the classroom. Niess's research on TPACK in pre-service mathematics teachers examines four components of professional development for pre-service mathematics teachers [48]. Such components are: (a) an overarching conception of teaching mathematics with technology, (b) instructional strategies and representation for teaching mathematics with technologies, (c) students' understanding, thinking, and learning in mathematics with technology, and (d) mathematics curriculum and curricular materials. From these four components, it can be concluded that a mathematics teacher—including pre-service mathematics teachers (PSMTs)—must be able to integrate technology as part of the implementation of the learning process—including the implementation of learning approach and assessment—to teach mathematical concepts more comprehensively. For example, when PSMTs practice teaching the concept of graphic of a quadratic function to students at the junior high school level using the Problem-Based Learning (PBL) model integrated with GeoGebra. To determine GeoGebra as the technology, they will integrate it into such teaching practice. They must already have Technological Knowledge (TK) related to the characteristics of GeoGebra and how well they master it. From this knowledge, they relate to Pedagogical Knowledge (PK) in the context of whether the GeoGebra software can be integrated into the PBL model. In addition, it is about how good students' skills are in operating GeoGebra. Furthermore, their technological knowledge is developed again with the Conceptual Knowledge e(CK) of a quadratic function, which in this context is whether GeoGebra is appropriate to visualize the quadratic function. Finally, combined with that knowledge, they can adequately teach the concept of quadratic function graphs through the PBL model integrated by GeoGebra.

C. Rational and the Purpose of the Study

One of the essential aspects in measuring the PSMT's TPACK in integrating technology during their teaching practice is the instruments used by the researchers. In a study, the research instrument determines the quality of the research methodology [49]. Therefore, there needs to be a study related to what instruments were used by previous researchers in measuring the PSMTs' TPACK skills, where one of the ways is to conduct a systematic literature review study to examine data and findings of other authors relative to a specified research question or questions [50]. Previous researchers have tried to study TPACK and pre-service teachers in a systematic literature review [51]. A systematic literature review was conducted on 37 research articles from ERIC, Scopus, and Web of Science databases from 2010 to 2020. The study examined the treatment of technologies that initial teacher education offers to early childhood and primary education pre-service teachers facing their practicum experiences. Nuangchalerm [52] conducted a systematic literature review of 11 research articles collected from the ASEAN Citation Index (ACI). The study identified and summarized the features of TPACK in ASEAN literature. Wang and Schmidt-Crawford *et al.* [53] conducted a systematic literature review of 88 research articles collected from ERIC, PsycINFO, and Mendeley TPACK Research Group from 2006 to 2015. This study analyzed pre-service teachers' TPACK development organized around five research methods (self-report measures, open-ended questionnaires, performance assessments, interviews, and observations). However, from those studies, the subjects studied were not specific to Pre-Service Mathematics Teachers (PSMTs). The SLR results that examine TPACK and PSMTs are similar to those of Yigit [54]. This study analyzed 45 articles from databases such as ERIC, JSTOR-Scholarly Journal Archive, and PsychINFO. However, Yigit [54] focused only on identifying PSMTs' development of the components of the TPACK framework, their perspectives for their future teaching, how their development of TPACK can be measured, and strategies to develop their TPACK. Therefore, based on previous empirical studies, this systematic literature review examines instruments used to measure the PSMTs' TPACK skills in integrating technology during teaching practice. The findings of this study are expected to be a reference for stakeholders in determining policies related to improving the skills of PSMTs in integrating technology during teaching practice. The research questions addressed in the study are as follows:

1) What kind of instruments are used to measure the PSMTs' TPACK ability?
2) Which references are used to develop measurement instruments for the PSMTs' TPACK in the technology integration?
3) What other frameworks are combined with the TPACK framework?

II. METHOD

This study uses a systematic literature review model to see the factors influencing PSMTs in integrating technology during teaching practice. Nightingale suggests that the first stage of conducting SLR is developing a protocol that clearly defines [55]: (1) the aims and objectives of the review, (2) the inclusion and exclusion criteria for studies, (3) how the study will be identified, and (4) the plan of analysis. Among those four definitions, the second point is the most critical in determining whether the SLR is well conducted. Nightingale uses six inclusion criteria which are (1) type of study, (2) type of participants, (3) type of intervention, (4) comparison, (5) outcome measures, and (6) other aspects related to the characteristic of the study [55]. To ensure that the protocol is well conducted, then Moher and Liberati *et al.* [56] suggests the concept of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyze), which consists of four stages of review, namely identification, screening, eligibility, and inclusion (see Fig. 3 for the PRISMA steps in this study).

A. Search Identification

The identification stage of this study was carried out by determining the keywords used to browse the needed research articles. The best article by the research objectives comes from a reputable database, range of years, and the (Population, Intervention, Comparison, Outcome) PICO principle—an abbreviation of Participant, Intervention, Comparison, and Outcome—used Mamédio and Santos *et al.* [57]. The database used in this study is the Scopus and Web of Science (WoS) database from 2012 to 2022. Both databases cover high-quality journals that publish high-quality research articles. In addition, Burnham also argues that WoS is over Scopus in terms of the depth of coverage, where the WoS database goes back to 1945 and Scopus goes back to 1966 [58]. However, those databases complement each other as neither resource is all-inclusive. The databases were prominent in educational technologies, and the publications found in these databases were scientific articles [59]. The next step is determining PICO, which enables the researchers to identify keywords for the systematic review in the various databases [60]. See Table II for the chosen keywords for each PICO component. Keywords defined in Table II are then used to find the desired research article using Boolean Operators such as AND and OR (see Fig. 3 for the search sample in Scopus). The articles were searched using Publish or Perish (PoP) software [61]. At this stage, there were 1,807 articles from the two databases.

Fig. 3. Sample of the search strategy.

B. Article Screening

This stage involves issuing research articles, not the desired publication type. Therefore, some articles of the type proceedings, review articles, and book chapters are deleted from the list. Proceeding-type articles are excluded since this type has a relatively limited scientific impact, their relative importance is shrinking, and they become obsolete faster than the scientific literature [62]. Next, review articles are also excluded since these articles do not convey the research results carried out empirically [63].

TABLE II: KEYWORDS BASED ON PICO PRINCIPLES

PICO Aspects	Keywords
Participants	"pre-service mathematics teachers", "pre-service mathematics teachers", "prospective mathematics teachers"
Intervention	"TPACK", "TPCK", "Technological, Pedagogical, Content Knowledge"
Comparison	"factors"
Outcome	"Technology integration"

Besides the article type aspect, the exclusion criteria are also based on the language used. At this stage, this research selects only articles written in English. English is an international language, making it easier for researchers to analyze and synthesize. The last criterion is excluding duplicated articles. Because this study uses two international databases, therefore duplication might be found. Based on this explanation, 666 articles were excluded, leaving 1,141 articles.

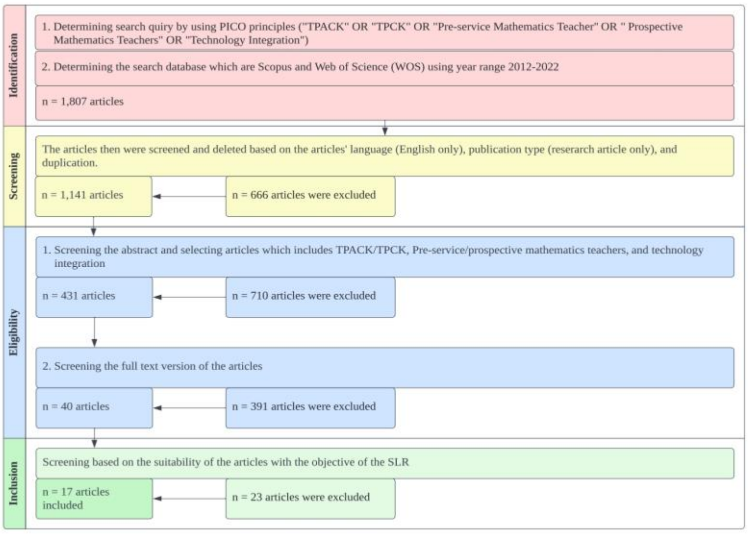

Fig. 4. Design of PRISMA steps.

C. Article Eligibility and Inclusion

The eligibility stage is achieved by selecting the articles based on the abstract and title. The title that only involves pre-service teachers and does not explicitly deal with PSMTs is not selected at this stage. One example is a research article from Baran and Canbazoglu Bilici *et al.* [64] entitled "Investigating the impact of teacher education strategies on pre-service teachers' TPACK." The article does not explicitly involve PSMTs as subjects in the study. Besides, a study from Valtonen and Leppänen *et al.* [65] titled "*Fresh perspectives on TPACK: pre-service teachers' appraisal of their challenging and confident TPACK areas*" also did not involve PSMTs as subjects in the study. Some of the articles issued are articles that do not contain TPACK/TPCK and PSMTs both in the article title and in the article abstract, such as research conducted by Parra and Raynor *et al.* [66]. Although it deals with TPACK, it does not involve PSMTs as the research subject. Furthermore, another study was the research of Undheim [67], which raised the topic of TPACK but did not involve PSMTs as the research subject. Based on the results of the title and abstract-based selection, there were 391 articles eliminated and 40 articles left.

The last step after the eligibility stage is the inclusion stage. This stage is carried out by analyzing the suitability of each article with the objectives of the SLR, which is related to the identification of instruments to assess PSMTs' TPACK. From the 40 articles selected at the eligibility stage, 22 articles were eliminated due to several causes, such as the research does not use a survey [68–72] and not focusing on TPACK assessment instruments [73–84], Design-Based Research type [85–87], and case study [88], [89]. As a result, the number of included papers is 17 to be further analyzed using NVIVO 12. The fundamental steps are visualized in Fig. 4.

III. Result

This section explains the analysis results related to the research questions. Based on the results of the PRISMA protocol, 17 articles were obtained (see Table III).

TABLE III: Listed Article Profile

Authors	Journal	Country	Number of Participants	Research Method
[90]	Technology, Pedagogy and Education	Ghana	104	Mixed-Method
[91]	International Journal of Research in Education and Science (IJRES)	Ghana	126	Quantitative
[92]	Educational Sciences: Theory & Practice	Turkey	52	Mixed-Method
[93]	The New Educator	USA	3 (sample)	Qualitative
[94]	International Journal of Technology in Mathematics Education	USA	51	Qualitative
[31]	Australian Journal of Teacher Education	Turkey	71	Mixed-Method
[95]	Eurasia Journal of Mathematics, Science and Technology Education	Spain	6	Quantitative
[96]	Mathematics Education Research Journal	Australia	373	Mixed-Method
[97]	Australian Educational Computing	Australia	18,690	Quantitative
[98]	Australasian Journal of Educational Technology	Tanzania	22	Quantitative
[99]	Educational Technology & Society	Turkey	427	Quantitative
[100]	International Journal of Mathematical Education in Science and Technology	Turkey	33	Qualitative
[101]	Educational Sciences: Theory & Practice	Turkey	407	Quantitative
[102]	Education Sciences	USA	175	Quantitative
[103]	Contemporary Educational Technology	Turkey	340	Quantitative
[104]	Interactive Learning Environments	Serbia	226	Quantitative
[105]	Journal of Research on Technology in Education	USA	315	Quantitative

A. Instruments Used to Measure the PSMTs' TPACK

Based on the results of the literature analysis conducted on the 17 articles, six types of instruments were used to measure the PSMTs' TPACK skills: the TPACK questionnaire, lesson plan rubric, observation form, interview, microteaching artifact, and other questionnaires. In general, the TPACK questionnaire is used by 88% of listed authors, of which another 12% use rubric lesson plans. In addition, 23% of listed authors used more than one instrument to measure the PSMTs' TPACK skills (see Table IV for details).

TABLE IV: TPACK Instruments Used by Previous Studies

	Instrument Used					
	TPACK Questionnaire	Lesson Plan Rubric	Observation Form	Interview Guidance	Microteaching Artefact	Other Questionnaires
[90]	√	√	√			√ (TAC)
[91]	√					
[92]	√		√	√	√	√ (CAMI & SES)
[93]	√					
[94]	√					
[31]	√			√	√	
[95]	√					
[96]	√					
[97]	√					
[98]	√					
[99]	√					
[100]		√				

	Instrument Used					
	TPACK Questionnaire	Lesson Plan Rubric	Observation Form	Interview Guidance	Microteaching Artefact	Other Questionnaires
[101]	√					
[102]		√				
[103]	√					
[104]	√					
[105]	√					
Total	15	3	2	2	2	2

Table IV shows the variation of instruments used by the authors to measure PSMTs' TPACK skills, where three authors use various instruments, namely [31, 90, 92]. Agyei and Voogt [90] used various instruments because this is inseparable from the efforts to answer the research question: "*how do the techniques used in the course on mathematics instructional technology affect the technology competencies (attitudes, knowledge, and abilities) of aspiring math teachers?*". Although they use four instruments, only three are used to measure the PSMTs' TPACK skills, while another is the Teachers' Attitude toward Computers (TAC) questionnaire adapted from research by Christensen and Knezek [106]. To answer the research question, they analyzed technology integration competencies by analyzing evidence in the PSMTs' lesson plans, lesson observation, and self-reports. To analyze TPACK in the lesson plan, they used the TPACK Lesson Plan Rubric adapted from the Technology Integration Assessment Rubric (TIAR) proposed by Harris and Grandgenett *et al.* [107]. Next, they adapted the TPACK Survey developed by Schmidt and Baran *et al.* [45] by using a 5-point Likert scale format in the questionnaire. One of the interesting aspects of this study is that [90] classified the TPACK component into three parts, namely the technology component using spreadsheets which includes TKss. The content component in mathematics includes CKmaths and TPCKmaths, and the pedagogy component uses activity-based learning and includes PK_{ABL}, PCK_{ABL}, TCK_{ABL}, and TPK_{ABL}. That way, they can distinguish the measurement aspects of the PSMTs' knowledge and skills. The last instrument used was the TPACK Observation Rubric, adapted from the TPACK-based Technology Integration Observation Instrument (TPACK-TIOI) developed by Hofer and Grandgenett *et al.* [108]. Adaptations were made so that TPACK observations could be carried out using spreadsheet-supported Activity-Based Learning (ABL) in mathematics consisting of 20 items with a 3-Likert scale.

Next, Aydogan Yenmez and Özpinar *et al.* [92] used six instruments in their research. Of the six instruments, only four are used to measure the PSMTs' TPACK skills. Based on their research objective, that is to examine the elements of microteaching as they are organized within the theoretical framework of TPCK, as well as the changes pre-service mathematics instructors encounter within the setting of TPCK, they use four instruments which are observation forms, microteaching videos, semi-structured interviews, and self-evaluation forms. At the same time, the two other instruments are the self-efficacy scale of Computer-Based Education, adapted from Arslan [109], and the Computer-Assisted Mathematics Instruction (CAMI) questionnaire, adapted from a study conducted by Yenilmez and Sarier [110]. Their observation form is used for peer evaluation between PSMTs during the teaching practice. The goal here is to improve the efficacy of microteaching by requiring pre-service teachers to use the criteria within the framework of components when assessing each pre-service teacher. The instrument used was microteaching videos to examine the change of each pre-service teacher along the axis of TPACK. Next, self-evaluation is used by passing it to the PSMTs for them to evaluate themselves related to TPACK components. This form consists of 22 questions made by shaping the observation form to allow for self-evaluation. Lastly, semi-structured interviews explore the data obtained from the self-evaluation form instrument. This can be noted from the research of Aydogan Yenmez and Özpinar *et al.* [92]; although they involved seven experts in validating the instrument, they did not describe based on what reference the instrument was developed and how the quantitative analysis of the instrument validity test was carried out.

Lastly, Kaya and Dağ [111] used three instruments to measure 71 Turkish PSMTs' TPACK skills in integrating technology during their teaching practice. The research aims to analyze PSTs' development of TPACK through a course implementation that was designed and implemented based on a TPACK framework. They used TPACK surveys, semi-structured interviews, and microteaching evaluation scales to answer this goal. The first instrument they used was the TPACK questionnaire which was adapted from an instrument developed by Kaya and Dağ [111]. The questionnaire showed that the overall sub-domains had alpha reliability coefficients between 0.77 and 0.88. The instrument used is a semi-structured interview consisting of six open-ended questions. This interview aims to investigate the PSMTs' development of TPACK in detail. They asked two mathematics education teachers to read the questions and confirm their clarity. The instrument used is the Microteaching Evaluation Scale (MTES) which was developed to obtain the required information related to microteaching performances of the PSMT concerning TPACK and course gains. The MTES was validated by two researchers who independently evaluated the scale based on common views.

Other authors were recorded to use only one type of instrument, namely TPACK surveys [70, 91, 94–97, 99, 101, 103–105, 112]. In addition, two authors who only used rubric lesson plan instruments as developed by Lyublinskaya and Kplon-Schilis [113] and Kartal and Çinar [114] were also recorded. The tendency of the listed authors to use the TPACK questionnaire to obtain data on the PSMTs' TPACK skills cannot be separated from the nature of the questionnaire that reaches people quickly, data accuracy, flexibility of time and place, scalability, and respondent anonymity [115].

B. References Used to Develop the Instruments

Instruments in a study determine the quality of the methodology and the research itself. Therefore, an instrument must have a basis in each of its components. Two of the ways are to adapt from existing instruments and adapt them to research needs. Another alternative is to develop the necessary instruments based on the theory developed in previous research. Since Table III indicates that the most widely used instrument is the questionnaire, this section only focuses on the references used to develop the questionnaires. Therefore, there are two articles whose instruments will not be discussed: the research article by Kartal and Çınar [100] and Lyublinskaya and Kplon-Schilis [113]. Both articles use rubric lesson plans as their primary research instruments, so the number of articles analyzed is 15. Based on the analysis results of the listed articles, nine previous studies have been used as a reference for adaptations of the TPACK questionnaire instrument. In addition, it was also noted that some authors chose to develop their TPACK questionnaires according to their research objectives. Fig. 5 illustrates the proportion of references used by the fifteen listed articles.

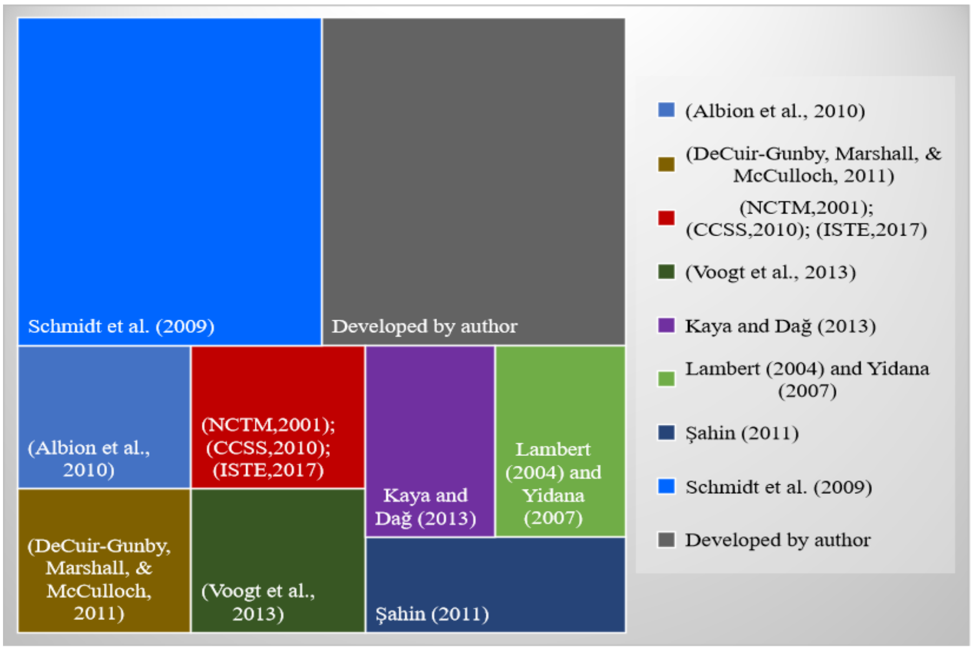

Fig. 5. Basis of research questionnaire development.

From Fig. 5, it can be seen that the instrument developed by Schmidt *et al.* [45] became the most adapted. However, Fig. 5 also shows that the number of researchers who develop their instruments is similar to those who adapt their instruments from Schmidt *et al.* [45]. Detail-adapted instruments and the self-developed instrument can be seen in Table V.

TABLE V: DETAILS OF ADAPTED AND SELF-DEVELOPED INSTRUMENTS

Authors	Type	References	Crobach's Alpha	EFA
[90]	A	[45]	0.700	Unexplained
[91]	A	[122, 123]	0.726	Unexplained
[92]	DA	N/A	Unexplained	Unexplained
[93]	A	[117]	Unexplained	Unexplained
[94]	A	[118–120]	Unexplained	Unexplained
[31]	A	[111]	0.770	√
[95]	DA	N/A	Unexplained	Unexplained
[96]	DA	N/A	Unexplained	Unexplained
[97]	A	[116]	0.970	√
[98]	A	[121]	0.812	Unexplained
[99])	A	[45]	0.940	√
[101]	A	[45]	0.890	√
[103]	A	[124]	0.830	√
[104]	DA	N/A	0.870	√
[105]	A	[45]	0.880	√

*A: Adapted; DA: Developed by Author; N/A: Not Applicable; EFA: Exploratory Factor Analysis

Table V shows the type of development questionnaire (adapted (A) or developed by the author (DA)), the reference used, the reliability level by Cronbach's Alpha, and Exploratory Factor Analysis (EFA). From the aspect of the type of development, as previously explained, most of the instruments developed are the result of adaptations from previous research carried out by Apeanti, Agyei and Voogt [91, 125]. From the reference aspect, the instrument developed by Schmidt and Baran *et al.* [45] is the most adapted compared to other reference instruments. Four studies [125, 126, 101, 127] are adapting the instrument questionnaire developed by Schmidt and Baran *et al.* [45]. However, none of them explains why they prefer to adopt the instrument developed by Schmidt and Baran *et al.* [45]. It may be because the instrument developed by Schmidt and Baran *et al.* [45] is intended to assess pre-service teachers' TPACK abilities, the same as the four studies' research subjects. Besides, four studies [92, 95, 96, 104] developed their TPACK questionnaire.

The next aspect is related to Cronbach's Alpha reliability level of the developed instrument. In general, several studies convey the level of reliability of the instruments developed where the minimum recorded level is 0.700 [125]. However, it was also noted that five studies do not include the level of reliability of the instruments developed. Interestingly, three studies developed their TPACK questionnaire instruments

[92, 95, 96], while two others are adapted instruments [70, 94]. In developing research instruments, the internal reliability test of an instrument (Cronbach's Alpha) is critical to verify that each test item is relevant to the issue under investigation [128]. In addition, in the context of the research article publication, the delivery of the reliability level of the research instrument can provide an overview to other researchers related to the quality of the instrument developed, which indirectly also describes the quality of the research methodology used and the results of the research.

The last aspect in Table V is conducting exploratory factor analysis (EFA) for the TPACK questionnaire development. In theory, factor analysis is a multivariate statistical procedure with three benefits. It is used to 1) compress a large number of variables into a smaller set of variables/factors, 2) establish underlying dimensions between measured variables and latent constructs, and 3) give valid evidence for self-reporting scales [129]. Next, EFA is a factor analysis that allows researchers to explore the main dimensions to generate a theory or model from a relatively large set of latent constructs often represented by a set of items [130–132]. Based on this understanding, the EFA is essential for researchers, especially in developing the TPACK questionnaire. Since the TPACK questionnaires developed in the listed articles are the result of development by the author and are the result of an adaptation of the instruments developed by his previous research—not entirely using it as it is—then EFA analysis is vital to do. Table IV shows that of the fifteen articles listed, 53% do not explicitly relate to the EFA analysis with details of three DA-coded articles; the rest are A-coded articles. The submission related to EFA analysis on the development of the TPACK questionnaire in a research article is important to do because it can provide and clarify information related to the construct validity of the instrument, even though the instrument is the result of an adaptation of previous research. For example, Karatas and Tunc *et al.* [99] stated in their research article that the TPACK questionnaire they used was an adaptation of Schmidt and Baran *et al.* [45] and was transliterated by Öztürk and Horzum [133]. Next, Karatas and Tunc *et al.* [126] added that the instruments they used had been tested EFA by Öztürk and Horzum [133] to determine the construct validity of the instruments. Thus, the information can indicate the quality of the adapted instrument. This became mandatory for researchers with DA codes because they developed the TPACK questionnaire they used. Thus, the questionnaire quality affecting the methodology and research results can be accounted for.

C. Other Framework Measured Besides TPACK

To get a holistic picture of the PSMTs skills of technological integration during their teaching practice, some previous researchers tried to combine TPACK with various frameworks. Based on the listed articles, some frameworks are integrated with TPACK, namely Teacher Acceptance towards Computers (TAC), Theory of Planned Behavior (TPB), Technology Acceptance Model (TAM), Perception Toward Technology (PTT), SAMR (Substitution, Augmentation, Modification, Redefinition), PoE (Perception of Effectivity) & PoB (Perception of Barriers), and self-efficacy & PCaE (Perception of Computer-assisted Education). However, there are still some articles that review TPACK only. See Fig. 6 for the details of the references of each additional framework.

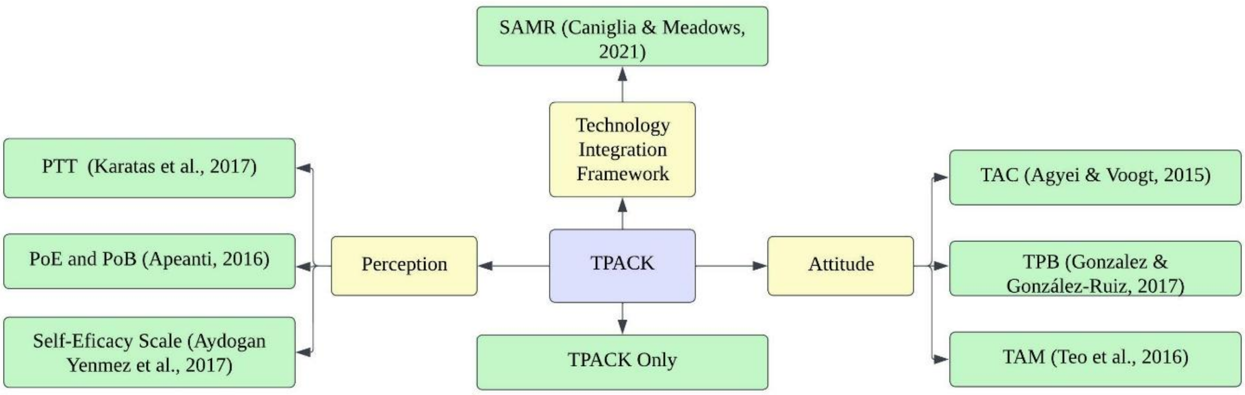

Fig. 6. Other Framework Integrated with TPACK.

The decision to integrate other frameworks with TPACK in measuring the skills of the PSMTs in integrating technology is based on the purpose of their research. From the listed articles, several researchers examined the PSMTs' technological integration from the aspect of attitude. Three frameworks appeared in the study to measure the PSMTs' attitude towards technology, which integrated the TAC framework [90]; the TPB [95]; the TAM [104]. The three studies have similarities in formulating questions and research objectives, namely the measurement related to the PSMTs' attitude toward technology. In theory, TAC is a framework used to measure PSTs' attitudes toward technology [106]. Next, TAM—an adaptation of TRA (Theory of Reasoned Action) proposed by Ajzen and Fishbein [134]—is the framework proposed by Davis [135] to measure an individual's acceptance and attitude toward technology. Lastly, TPB is a theory proposed by Ajzen (1991) that aims to measure student's—in this term, the pre-service mathematics teachers—persistence intentions. Within the TPB framework, a particular component examines individuals' attitudes toward anything. The relationship between the three theories/frameworks relates to measuring individuals' intention toward anything, which in the context of TPACK becomes intention toward technology; each framework has an attitude component. Therefore, it can be understood why the three studies use one of the frameworks.

In addition to measuring attitude factors, several listed researchers measure the PSMTs' technological integration skills from perception. In Fig. 6, four types of perception measurements are recorded through several theories from previous research, such as (1) PTT (Perception Toward Technology) proposed by Öksüz and Ak *et al.* [137]; (2) PoE (Perception of Effectiveness) and PoB (Perception of Barriers) contained in Teaching with Technology Instruments (TTI) that adapted and modified from Yidana, Sahin [122, 123]; and (3) self-efficacy perception in computer-based education which is contained in Self-Efficacy Scale proposed by Arslan [109]. Perception analysis is essential because how an individual sees an object can determine how the individual behaves and provide treatment for the object [138]. Thus, it can be concluded that the relationship between PSMTs' perception, TPACK skills, and technological integration during teaching practice lies in the PSMTs' willingness to integrate technology during teaching practice based on how they perceive technology and how well they master the TPACK framework. This is seen in the research of Karatas and Tunc *et al.* [99], who want to see how the PSMTs' technology is used through the PTT aspect. Similarly, Apeanti [91] uses PoE and PoB aspects in the TTI instrument, and Aydogan Yenmez and Özpinar *et al.* [92] uses the Self-Efficacy Scale to see the PSMTs' perception toward technology use.

Fig. 6 also shows that TPACK can be integrated with other technology integration frameworks, such as SAMR, by Caniglia and Meadows [94]. In theory, SAMR is a framework proposed by Puentedura [23] to facilitate the acquisition of proficiency in modern technologies. In the context of the research of Caniglia and Meadows [94], the integration of TPACK and SAMR is used for particular purposes corresponding to each framework. TPACK provides a framework for integrating technology across the curriculum, while the SAMR model provides insight into how the digital-based learning media chosen by PSMTs may affect teaching and learning.

IV. Discussion and Conclusion

Technology integration skills for PSMTs are critical in successfully implementing their teaching practices. In addition to helping them learn more effectively and efficiently, these skills can also help them communicate material better and validly through visualization or simulation of abstract mathematical objects. So, the effort to measure the skills of PSMTs in integrating technology into the practice of teaching mathematics is an excellent first step. However, studies related to measurement instruments carried out by previous researchers were deemed necessary to provide insight to subsequent researchers regarding alternatives and variations of what instruments could be used in measuring the PSMTs' technological integration skills, especially those based on the TPACK framework. In addition, as explained in the introduction section, systematic literature review research that examines PSMTs' technological integration skill measurement instruments from the TPACK framework aspect is still limited, so the findings of this study can fill in the gaps.

The first concern in this study is the type of instrument used by the authors. The TPACK questionnaire is the most widely used instrument for measuring PSMTs' technological integration skills, followed by three authors' rubric lesson plans. The exact number of users are observation form instruments, interview guidance, and microteaching artifacts (such as video). The ease of using questionnaires in collecting data is one of the considerations of the listed researchers. This is in line with the opinion of Jenny and Diesinger [139] that a self-administered questionnaire, which is simple to use and has answers that can be mailed, is helpful for large-scale assessments. Next is the use of the rubric's lesson plan, which three researchers used, namely [90, 100, 102]. Based on the analysis of the three articles, it was found that the measurement of the PSMTs' technological integration skills through TPACK was carried out during the PSMTs conducting microteaching or instructional practice reviewed from the lesson plan developed by the PSMTs. Therefore, the instrument is an appropriate alternative technological integration skill measurement tool. This is in line with what was done by Kereluik and Casperson *et al.* [140], where they used a rubric's lesson plan to see the skills of PSTs in integrating technology in terms of the lesson plan that has been developed. The last is observation form instruments, interview guidance, and microteaching artifacts. These three instruments are supporting instruments to strengthen the questionnaire used as the main instrument. Likewise, Agyei and Voogt [90] used the observation form to deepen the data obtained from the rubric's questionnaire and lesson plan. Durdu and Dag use interviews and microteaching artifacts to synchronize and deepen the data obtained from the questionnaires that have been distributed [31].

The next aspect is the reference used to develop the instruments, specifically in the TPACK questionnaire development. As already explained, the instrument developed by Schmidt and Baran *et al.* [45] became the most widely referred reference for developing the TPACK questionnaire. Apart from the same research subjects—namely at the level of pre-service teachers—the instruments developed by Schmidt and Baran *et al.* [45] have been statistically tested both from the aspect of internal reliability using Cronbach's Alpha, as well as construct validity with varimax rotation within each knowledge domain. Several previous researchers who studied TPACK skills at the level of pre-service teachers using questionnaires also adapted instruments developed by Schmidt and Baran *et al.* [45]. Ritzhaupt and Huggins-Manley *et al.* [141] adapted an instrument that Schmidt developed to measure the TPACK skills of The US' PSTs [45]. Next, Tondeur and Scherer [142] also adapted the TPACK questionnaire developed by Schmidt and Baran *et al.* [45] and combined it with the TPACK self-report scale developed by Scherer, J. Tondeur *et al.* [143] to measure 688 Belgian pre-service teachers' TPACK skills through an online survey. Lastly, Kotzebue [144] adapted the TPACK questionnaire developed by Schmidt and Baran *et al.* [45] to analyze the TPACK skills of 206 Austrian biology PSTs combined with a biology-specific self-report. Thus, it can be concluded that the TPACK questionnaire developed by Schmidt and Baran *et al.* [45] became an alternative reference to the appropriate instrument for measuring PSTs' TPACK skills.

Other instrument references, such as those developed by Albion and Jamieson-Proctor *et al.* [116], have the same subject level, i.e., PSTs. However, his developed instruments led to the TPACK Confidence Survey (TCS). The TPACK-TCS includes items that assess teachers' attitudes about utilizing ICT, their confidence in using ICT for teaching and learning tasks (TPACK), their proficiency with ICT, their Technology Knowledge (TK), and their TPACK Vocational Self-efficacy. Thus, this instrument can be an alternative to be adapted to measure the psychological aspects of the PSTs regarding the TPACK framework. Another alternative to the TPACK survey instrument reference that can be used is the one developed by Sahin [124]. This instrument has the same target level of research subjects, namely pre-service teachers. However, the question asked is relatively more technical, as seen in the list of statements on technological knowledge [124]. At that point, the TK statements developed led to the technical mastery of computer devices, resulting in many questions that were not holistic. Examples include "I know about communicating through Internet tools (ex., e-mail, MSN Messenger)". This type of question becomes inflexible because technology will continue to evolve.

In contrast to the TK statements developed by Schmidt and Baran *et al.* [45], it is more general, such as "*I can learn technology easily*". This makes adapting the instrument developed by Schmidt and Baran *et al.* [45] more accessible. Next, this section does not discuss and examine the instrument references [111, 117, 121–123], because the author does not provide accessible instruments. So, it is not discussed further.

The last aspect discussed in this section is the other framework integrated into the TPACK framework to measure the PSMTs' technological integration skills. The context of perception (PTT, Self-Efficacy Scale, and Perception of Effectivity & Perception of Barriers) and attitude (TAM, TPB, and TAC) are often associated with the TPACK framework, followed by the context of the Technology Integration Framework (TIF), namely SAMR. Some previous researchers defined the two terminologies differently in the context of perception and attitude. According to Allport [145], an attitude is a mental or neurological state of readiness that is organized by experience and has a directive or dynamic impact on the individual's behavior toward all objects and circumstances to which it is linked. Individuals' attitudes affect their decisions, drive their conduct, and influence what they selectively recall (not always the same as what we hear). Attitudes come in various strengths, and they, like most things taught or impacted by experience, may be assessed and modified [146].

Meanwhile, perception is how organisms interpret and arrange sensations to form a meaningful experience of their surroundings [147]. In other words, a person is presented with a scenario or stimulus. Based on earlier experiences, the person interprets the inputs as something significant to him or her. However, what a person thinks or sees may differ significantly from reality [148]. Based on these two explanations, it is very natural that TPACK researchers embed aspects of perception and attitude as part of measuring individual skills—in the context of this study, PSMTs—in integrating technology into a learning process. Some previous studies have also tried to integrate TPACK with the attitudes embedded in the TPB [142, 149, 150], and perception aspects [151–154].

On the other hand, SAMR is recorded as a TIF integrated with TPACK in research by Caniglia and Meadows [94]. In the study, SAMR was used as a comparison to TPACK. Whereas TPACK provides a framework for integrating technology across the curriculum, the SAMR model provides insight into how the websites chosen by PSTs may affect teaching and learning. Several previous studies have combined TPACK and SAMR, such as those conducted by Hilton [155] using both frameworks to see the effectiveness of iPad use in future social studies learning.

From all these discussions, it can be concluded that the TPACK Questionnaire is the most widely used instrument in previous research related to efforts to measure the PSMTs' TPACK skills in integrating technology during teaching practice. Next, the instrument developed by Schmidt and Baran *et al.* [45] was found to be the most adapted by previous researchers as an alternative instrument to measure the PSMTs' TPACK skill. Finally, context-based and perception contexts are the most integrated with TPACK-based measurement frameworks.

This study still leaves some space for further research. Some of them are from the field aspect because this research cannot only focus on research on pre-service mathematics teachers. Thus, systematic literature review research can be done on TPACK instruments used to measure PSTs' technological integration skills in other fields. It is expected that the results of this study can provide insight to subsequent researchers on what instruments can be used to measure PSMTs' TPACK, which research instruments can be used as references, and what frameworks/factors can be integrated with TPACK instruments.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

N.I. conducted the data collection and analysis and wrote the paper; S.H.H. conducted the content and format review; and R.A.R. conducted the format and content review; all authors approved the final version.

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