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Analysis of TPACK Incorporated Learning Devices: An Exploratory Descriptive Study of Mathematics Teachers

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ABSTRACT

Several studies are examining the problem of mathematics learning devices, but few have specifically explored the devices that are incorporated with technological pedagogical content knowledge (TPACK). Therefore, this study aims to descriptively explore the incorporation of TPACK in mathematics learning devices. An exploratory descriptive method was used to achieve the objective of the analysis. Participants were 36 mathematics teachers, aged 30–50 years, and more than five years of teaching experience. Following the process, the instruments used during the analysis were learning device assessment sheets and interview guidelines. The data obtained were analyzed using quantitative analysis to identify the criteria for learning devices. The results showed that the criteria for TPACK incorporation in mathematics learning devices were medium and low. These signified that mathematics teachers had not optimally incorporated TPACK into learning devices. Despite learning devices meeting the feasibility aspect, the language criteria were high, and the presentation as well as graphic criteria were high and medium. A total of four competencies were targeted in learning devices, namely critical thinking, creativity, communication, and collaboration. The results of this study recommended that TPACK-incorporated mathematics learning devices be implemented in schools.

Keywords: exploratory descriptive, mathematical competence, mathematics learning devices, TPACK

INTRODUCTION

Mathematics is the mother of science, as explained by Kuma (2012) and Situngkir and Dewi (2022). This is because the subject forms the basis for the development of nearly all branches of science (Isnawan et al., 2024; Sukarma et al., 2024; Thorat, 2024). It also serves as a language used to explain various phenomena in life (Campanilla et al., 2024), and functions as a device to help humans solve diverse life problems (Alsulami et al., 2023; Isnawan and Alsulami, 2024). In this context, mathematics becomes a compulsory subject in schools at all levels of primary and secondary education.

Learning mathematics proceeds smoothly (Isnawan et al., 2024), but several recent studies show that various challenges are being encountered (Boaler et al., 2018; Huang and Shimizu, 2016; Olivares, 2024). These issues include low mastery of mathematical concepts among students (Elia et al., 2016; Haj-Yahya, 2022; Sreylak et al., 2022) and limited skills of teachers in developing effective mathematics learning devices (Hoadley and Campos, 2022; Supriadi, 2019; Yerushalmy et al., 2017). Several previous studies have also shown that some mathematics teachers tended to conduct learning according to the instructions of the textbook or rarely designed a personal learning model (Li et al., 2024; Njiku et al., 2021). Moreover, teachers have rarely incorporated technological pedagogical content knowledge (TPACK) into learning devices (Li and Li, 2024; Rakes et al., 2022).

Table 1. Differences between current and previous studies

Study article	Object of study	Learning incorporation	Participants	Study design
Tang et al. (2023)	Mobile learning	-	-	Systematic literature review
Putri et al. (2019)	Learning device	RME	Junior high school students	Development study (Dick and Carey Model)
Güler et al. (2022)	Mobile learning	-	-	Meta-analysis
Current study	Learning device	TPACK	Mathematics teachers	Exploratory descriptive

Numerous studies examine the skills of mathematics teachers in designing learning devices (Güler et al., 2022; Putri et al., 2019; Tang et al., 2023), but few explore devices that incorporate TPACK. Relating to this discussion, TPACK has offered a useful framework to help maximize the quality of learning mathematics (Njiku et al., 2021; Rakes et al., 2022). Technology has been incorporated into TPACK without sacrificing the core of mathematical education and content (Esposito and Moroney, 2020; Nuraina and Rohantizani, 2024). By offering a variety of visual presentations that give abstract mathematical concepts and formulas more substance, technology has assisted students in creating these ideas (Bonafini and Lee, 2021; Morales-López et al., 2021). Tang et al. (2023) used a systematic review design to test the effectiveness of mobile learning in improving learning outcomes. The results showed that most mobile education optimized learning outcomes, motivation, and interaction among students during learning, although some applications have caused a significant cognitive load for students.

Putri et al. (2019) developed a learning device based on realistic mathematics education (RME) to optimize spatial abilities and learning motivation among students, using a development study design. The results showed that RME learning device proved effective in improving spatial abilities and learning motivation among students, receiving positive responses, and associating learning time allocation with the conventional period. In another review, Güler et al. (2022) used a meta-analysis design to analyze the impact of mobile learning on mathematics learning outcomes among students. The study showed that mobile learning optimized results in students, even though it has been greatly influenced by mathematics material being learned.

A comparison between several previous explorations and the current study is shown in **Table 1**. The studies use systematic literature review designs, meta-analysis, and development models to address objectives related to learning devices. Meanwhile, this study uses an exploratory descriptive design to investigate the incorporation of TPACK in learning devices. Participants used are mathematics teachers, interacting directly with students during learning (Sevimli and Ünal, 2022).

Based on the previous description, the purpose of this study is to descriptively explore mathematics learning devices, particularly those prepared by teachers. To achieve the objective, the analysis formulates several study questions as follows:

RQ1: What is the description of TPACK criteria in mathematics learning devices?

RQ2: What is the description of the feasibility criteria for mathematics learning devices?

RQ3: What is the description of the competency targets in mathematics learning devices?

METHOD

Study Design

The design used was exploratory descriptive, which was selected because this study aimed to describe the phenomenon (Campanilla et al., 2024; Hunter et al., 2019; Lee et al., 2018; Souza Pinto et al., 2017) concerning the ability of mathematics teachers to prepare TPACK-incorporated learning devices. A total of two aspects were used to describe this phenomenon, namely the aspects of TPACK and mathematical skills that learning devices aimed to optimize. The procedure implemented during the analysis included several steps (Hunter et al., 2019; Sakyi et al., 2020), such as identifying problems as well as study objectives, selecting participants, designing instruments, collecting data (observation and interviews), analyzing data (averages and categories), interpreting results, as well as compiling reports and conclusions.

The analysis started by identifying the issues educators encountered when teaching mathematics to determine the problems and objectives of this study. Poor TPACK incorporation in learning devices was an issue encountered during the process. This study then established the objectives, examining TPACK in connection with teacher-made learning devices. The next task was the selection of a school where participants would be accommodated, and the formation of educational devices by teachers was followed. Semi-structured interviews and observation were conducted to gather data, which was later examined as well as interpreted concerning the study questions. A report as well as a review of the results was the final step, and the study procedure was shown in **Figure 1**.

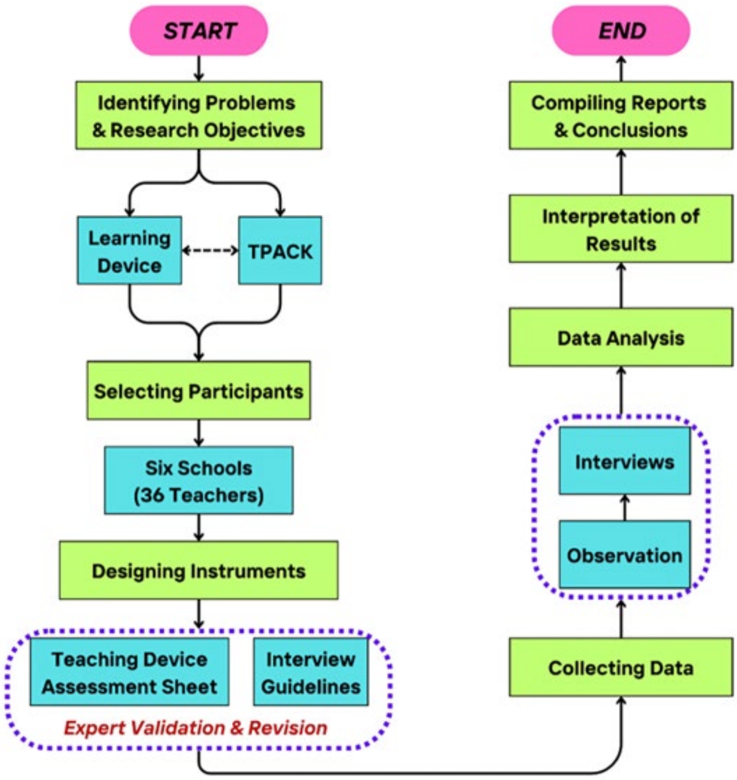

Figure 1. Study procedures

Participants

Thirty-six mathematics teachers from six Indonesian junior high schools (West Lombok Regency) participated in this study, and the institutes were categorized as *Driving School*. As a type of school digitization, an institute mandating that teachers should form learning resources incorporating TPACK was known as a "*Driving School*." Since participants were dispersed in various schools, the cluster sampling method was used for selection. Additionally, the people included those with more than 5 years of experience teaching mathematics, ranging from 30 to 50 years of age.

Instrumentation

The main instrument used in this study was a learning device assessment sheet. Learning devices comprised two types, namely *Microsoft PowerPoint*-based learning media and student worksheets (LKPD). Moreover, the instrument used aspects of TPACK and mathematical skills as the assessment indicators. The assessment sheet was applied during the analysis to evaluate learning devices prepared by mathematics teachers. During the process, *a Likert scale* with four levels-4 (very good), 3 (good), 2 (poor), and 1 (very poor)-was applied in the evaluation. A four-point scale was selected to simplify the assessment process and minimize assessor indecision (Croasmun, 2011; Koo and Yang, 2025). The analysis also used interview guidelines as an additional instrument in this study. These guidelines were intended to confirm the results obtained from the assessment sheet before concluding (Brown and Danaher, 2017; Deterding and Waters, 2018; Husband, 2020).

Data Analysis Procedure

The data obtained were analyzed quantitatively by calculating the average score of the assessment results. Quantitative analysis was used because it objectively assessed learning devices prepared by teachers and supported the generalization of the results, allowing the devices to be used in a broader context. After obtaining the average score, it was categorized into three levels, namely low (1.00–1.99), medium (2.00–2.99), and high (3.00–4.00) (Iskandar et al., 2021; Rahmatullah et al., 2021). The average score was analyzed separately for each participant based on the school of origin. Moreover, the analysis used codes to represent each school, namely A1, A2, and A3. To support the assessment process, three experts in education, learning technology, and instructional design were enlisted.

Table 2. TK criteria in mathematics learning devices

Statement items	Average		
	A1	**A2**	**A3**
PowerPoint used attractive templates, slide animations, and other features, making the education lively for teachers during learning activities.	3.57	2.30	1.00
PowerPoint was arranged according to the flow of learning activities.	3.07	2.10	1.00
No problem was encountered with PowerPoint that was arranged.	3.36	2.10	1.00
Educators adjusted the use of learning aids, media, or software appropriately, which were applied simultaneously with PowerPoint teaching media.	2.86	2.20	1.00
Average	3.22	2.18	1.00
Criteria	High	Medium	Low

Figure 2. Example of TK incorporation in mathematics learning devices

Table 3. PK criteria in mathematics learning devices

Statement items	Average		
	A1	**A2**	**A3**
PowerPoint was arranged according to the Competency Achievement Indicators (IPK) and learning objectives.	3.36	2.30	1.00
PowerPoint was arranged using various learning strategies.	2.93	2.00	1.00
PowerPoint that was arranged contained an apperception used in providing an introduction or initial stimulus relevant to the material to be studied.	2.86	2.10	1.00
PowerPoint that was arranged included interactive types, having interaction between teachers and students for easy understanding of the material presented.	2.64	2.10	1.00
Average	2.95	2.13	1.00
Criteria	Medium	Medium	Low

RESULTS AND DISCUSSION

Results

RQ1. What is the description of TPACK criteria in mathematics learning devices?

During this section, the analysis assessed learning devices prepared by mathematics teachers. The process used the components of TPACK as aspects in the assessment. The average scores and criteria for learning devices were shown in Table 2 which was related to technological knowledge (TK) aspect. The table showed that the criteria for the teaching devices reviewed from TK aspect varied. Through the evidence of analysis, the three groups had different levels, including low (A3), medium (A2), and high (A1). These results showed that learning devices contained high technological aspects against A1, medium for A2, and low for A3, respectively.

An example of TK incorporation in learning devices prepared by teachers was shown in Figure 2. The excerpt of learning device used technology in the form of an educational video embedded in a QR code to be watched by students during learning. Moreover, learning video contained interesting content related to the concept of function. The video screening was expected to increase understanding among students that functional material has benefits in life. By knowing these benefits, students were expected to become interested in learning, having attention and motivation, as well as being positive toward mathematics education.

The category of learning devices formed by mathematics teachers was shown in Table 3, viewed from PK aspect. The pedagogical aspects of learning devices created by mathematics teachers had not met high criteria as

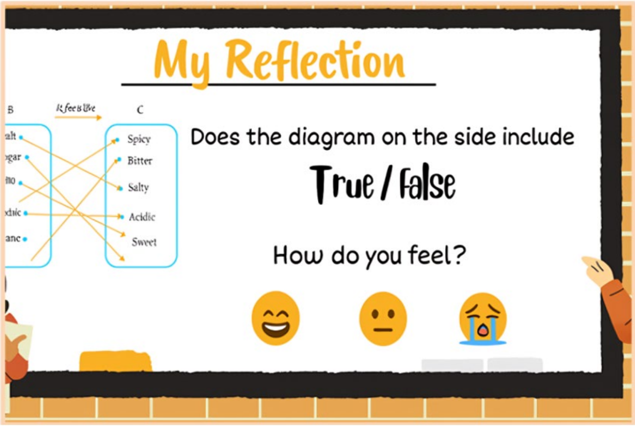

Figure 3. Examples of PK incorporation in mathematics learning devices

Table 4. CK criteria in mathematics learning devices

Statement items	Average		
	A1	**A2**	**A3**
PowerPoint prepared contained questions shown as evaluation material for understanding of students to understand the teaching material that had been delivered.	3.43	2.20	1.00
Teachers provided feedback to students related to the evaluation questions shown on PowerPoint teaching media.	2.50	2.30	1.00
Teachers used various assessments when presenting teaching materials using PowerPoint media.	3.00	2.30	1.00
Average	2.98	2.27	1.00
Criteria	Medium	Medium	Low

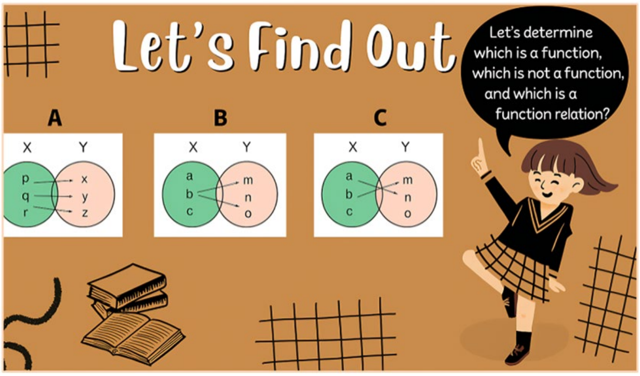

Figure 4. Example of CK incorporation in mathematics learning devices

also shown in the table. A total of two school groups only reached the medium criteria (A1 and A2), and the other group was in the low category. These results showed that pedagogical aspects needed to be optimized by mathematics teachers when compiling learning devices.

Figure 3 showed an example of a snippet of PK incorporation in learning devices, representing the reflection activities contained in learning device. The activities were an important pedagogical aspect in learning relating to the student-centered learning evaluation process. The reflection aimed to improve the quality of learning in the future (Isnawan et al., 2024). In addition, the activities used included two types, namely reflection on the concept of function and feelings of students. Reflection on the concept of function was intended to confirm how the purpose learned by students had been achieved. Meanwhile, consideration of the feelings of students was related to how students felt after learning. This reflection was conducted to confirm that learning device attracted the interest of students or generated positive motivation during studying.

In relation to CK aspect, the criteria for learning devices developed by mathematics teachers were the same as the criteria for PK aspect. During the analysis, A1 as well as A2 had medium criteria, and A3 had low criteria. In essence, none of mathematics teachers from the six schools had high criteria. Complete results related to CK aspect were shown in **Table 4**.

A selection of CK developed by teachers was shown in **Figure 4**, representing the use of mathematical content or materials in learning devices. During the process, teachers presented three examples of mapping from domain X to codomain Y. Using the three examples, teachers asked students to determine which mapping was a function,

Table 5. TPK criteria in mathematics learning devices

Statement items	Average		
	A1	A2	A3
Teachers created PowerPoint that made students more active during learning activities, such as by displaying trigger questions.	2.64	2.10	1.00
PowerPoint that was created already used game-based learning applications such as Quizizz, Kahoot, and Word Wall.	3.14	2.10	1.00
Average	2.89	2.15	1.00
Criteria	Medium	Medium	Low

Table 6. TCK criteria in learning devices

Statement items	Average		
	A1	A2	A3
Teachers selected teaching aids or supporting media used simultaneously with PowerPoint teaching media to help pupils understand the concepts and theories contained in the material presented.	2.79	2.20	1.00
Teachers compiled PowerPoint by developing activities and assignments that incorporated technology among students.	2.86	2.10	1.00
Average	2.82	2.15	1.00
Criteria	Medium	Medium	Low

Table 7. PCK criteria in mathematics learning devices

Statement items	Average		
	A1	A2	A3
Teachers generated PowerPoint by making difficult learning materials easy to understand for students.	3.14	2.30	1.00
The compiled PowerPoint already contained images/graphics, videos, and audio, allowing the delivery of teaching materials to be clearer.	3.21	2.20	1.00
The compiled PowerPoint already contained questions used as independent assignments to test the abilities of students related to the material that had been presented.	3.29	2.30	1.00
The compiled PowerPoint directed students to think about analyzing the material presented.	3.86	2.30	1.00
Average	3.13	2.28	1.00
Criteria	High	Medium	Low

Table 8. TPACK criteria in mathematics learning devices

Statement items	Average		
	A1	A2	A3
PowerPoint was arranged according to learning method used, which allowed learning objectives to be achieved.	2.64	2.30	1.00
Teachers assessed the results of work done by students using various studies after delivering teaching materials with the help of PowerPoint media.	2.85	2.20	1.00
Teachers arranged PowerPoint teaching media that were adjusted to the use of teaching materials or other teaching aids, allowing learning process to run smoothly and learning objectives to be achieved.	3.07	2.30	1.00
Average	2.86	2.27	1.00
Criteria	Medium	Medium	Low

not a function, and a functional relation. This activity was expected to enable students to understand the differences between functions, non-functions, and function relations through a form of mapping representation, respectively.

The results of this study in the combined aspects, such as TPK, were shown in **Table 5** which were also the same as PK and CK aspects. During the analysis, A1 as well as A2 had medium teaching device criteria, and A3 had low criteria. These results tended to be similar because TPK component was formed from two components, namely TK and PK.

Since TCK was formed from TK and CK aspects, the results were uniform with TPK. **Table 6** shows that A1 and A2 compiled learning devices with medium TCK criteria, while A3 was included in the low criteria.

As for PCK aspect, the criteria for teaching devices compiled by mathematics teachers were high (A1), medium (A2), and low (A3). **Table 7** showed the criteria for each school group during the analysis.

Table 8 shows the criteria for learning devices reviewed from the total TPACK aspect. The analysis explained that mathematics teachers from A1 and A2 school groups had medium criteria, while A3 had low criteria.

Table 9. Criteria for content feasibility of mathematics learning devices

Statement items	Average		
	A1	**A2**	**A3**
Mathematics teachers present material in LKPD according to learning outcomes, learning objectives, and learning objective flow.	3.79	3.55	3.50
Mathematics teachers present accurate material in LKPD from the latest sources, such as books, journals, and various other learning sources.	2.93	3.05	1.50
Mathematics teachers present material in LKPD sequentially and in a structured manner that can help students find a concept.	3.93	3.55	1.50
Mathematics teachers create contextual problems in LKPD to find a concept according to learning materials.	3.43	3.25	1.50
Mathematics teachers compile LKPD with types of activities in it to develop understanding of students.	3.71	3.55	1.50
Facilitate students in drawing conclusions related to the material presented in LKPD.	2.64	2.75	1.00
Mathematics teachers select the right technology in LKPD (teaching aids/media/software) according to the material presented.	2.93	1.55	1.00
The technology used in LKPD is easy to operate.	3.57	1.75	1.00
The technology used in LKPD is attractive to students.	3.57	1.70	1.00
The technology used in LKPD inspire active participation by students.	3.57	1.70	1.00
Average	3.41	2.64	1.45
Criteria	High	Medium	Low

Table 10. Criteria for the language feasibility of mathematics learning devices

Statement items	Average		
	A1	**A2**	**A3**
Mathematics teachers compiled LKPD with spelling according to Indonesian language rules.	3.71	3.86	3.50
Mathematics teachers gathered LKPD using standard terms.	3.93	3.90	3.94
Sentences used in LKPD did not contain double meanings.	4.00	3.86	3.89
Mathematics teachers compiled LKPD using language that was easy to understand.	3.86	3.86	3.83
Average	3.88	3.87	3.79
Criteria	High	High	High

Table 11. Presentation criteria for the feasibility of mathematics learning devices

Statement items	Average		
	A1	**A2**	**A3**
Mathematics teachers compiled an interesting LKPD.	3.29	2.95	3.00
Mathematics teachers gathered clear instructions for using LKPD.	3.71	3.00	4.00
Mathematics teachers compiled LKPD by presenting the time allocation for working on LKPD.	3.79	2.14	2.50
Instructions given in LKPD were clear.	3.50	3.33	3.50
Average	3.57	2.86	3.25
Criteria	High	Medium	High

RQ2. What is the description of the feasibility criteria for mathematics learning devices?

Learning device that was assessed for feasibility criteria in this study was LKPD, as several aspects of possibility were evaluated, including the first known as content feasibility. Based on the analysis results, information was obtained that A1 mathematics teachers compiled LKPD with high criteria, A2 had medium criteria, and A3 had low criteria. **Table 9** shows the criteria for each school group. Following the discussion, LKPD was a worksheet of students created by mathematics teachers. The second aspect was language, with analysis showing that all learning devices met high criteria. All participating mathematics teachers compiled LKPD with using appropriate language, as shown in **Table 10**.

The third aspect was presentation feasibility, where the analysis results showed that mathematics teachers from A1 and A3 had high learning device criteria, while A2 had medium criteria. **Table 11** shows the average score for each participant during the process.

The analysis results conduct during the process associated with the feasibility study. Mathematics teachers from A1 and A3 developed learning devices with high graphic feasibility, while A2 medium criteria, as shown in **Table 12**.

Table 12. Graphic feasibility criteria for mathematics learning devices

Statement items	Average		
	A1	A2	A3
Mathematics teachers compiled LKPD with an attractive cover design by the contents of LKPD.	2.86	2.20	3.00
Suitability of color gradation used in LKPD.	3.71	2.60	3.00
The use of fonts (type and size) made the presentation easier for readers to understand the contents of LKPD.	3.29	3.10	3.00
Harmony of text and image layout in LKPD	3.64	2.95	3.00
Mathematics teachers selected interesting images in LKPD to attract students to learning activities.	3.57	2.70	3.50
LKPD print quality was good and colorful.	3.93	3.15	4.00
Average	3.50	2.78	3.25
Criteria	High	Medium	High

Table 13. Mathematical competency targets in mathematics learning devices

Mathematical competence	Description
Critical thinking	In PowerPoint created by mathematics teachers, most teachers design problems that train students to solve issues, such as in the topics of quadratic equations and algebra. In TPACK-incorporated LKPD designed by mathematics teachers are able to create contextual problems with various activities included in LKPD that help students discover concepts. Additionally, students are asked to identify related information about the material presented through instructional videos aimed at improving the ability to identify and analyze a problem. Examples include the material on flat-sided space geometry, mutually exclusive events, independent events, and algebra.
Creativity	Mathematics teachers are able to design PowerPoint that adapts the use of supporting media to develop creativity of students, and use applications such as Quizizz to evaluate the understanding. Teachers are capable of forming innovations using technology in LKPD. The technology used includes teaching aids, Quizizz, hyperlinks, instructional videos, and barcodes. The use of this technology aims to train technological skills of students, forming more engaging and less monotonous learning activities. Moreover, creativity in LKPD can be observed in the variety of technology used, the diversity of activities included, the variety of learning resources, and the ability to apply the 5M (observing, asking, trying, reasoning, and communicating) learning process.
Communication	Mathematics teachers are excellent at directing students to answer example problems shown in PowerPoint. The teachers are capable of designing LKPD while paying attention to communication skills. This can be observed from the usage instructions of LKPD and the content. Examples include clear instructions in LKPD, facilitating students in drawing conclusions related to the material taught, and facilitating students in presenting work results. Additionally, the communication aspect in LKPD can include using media and technology to express the material taught.
Collaboration	In PowerPoint designed by mathematics teachers, some are able to form interactive PowerPoint that optimizes the interaction between teachers and students. The collaboration aspect can be observed from the group formation in completing LKPD. This is expected to show effective teamwork skills among students and the ability to help each other in solving problems presented in LKPD. Furthermore, the collaboration aspect can be observed when teachers and students conclude the material taught.

RQ3. What is the description of the competency targets in mathematics learning devices?

Based on mathematical competence aspect, this study showed several mathematical competencies that were the targets of learning devices formed by mathematics teachers. **Table 13** shows several mathematical competencies included in learning devices. Additionally, **Table 13** presented that a total of four competencies were targeted. A total of four mathematical competencies were developed during the analysis, namely critical thinking, creativity, communication, and collaboration.

Discussion

The results showed that TPACK criteria in learning devices compiled by mathematics teachers were, on average, in the medium (A1 and A2) and low (A3) categories. This was associated with the study of Nuraina and Rohantizani (2024), who explained that mathematics teachers tended to experience significant challenges when compiling materials incorporating TPACK. The outcomes were also in agreement with several previous studies, signifying that challenges arose when compiling mathematics materials, even though teachers already knew technology (Bonafini and Lee, 2021; Morales-López et al., 2021). Knowledge of technology was a prerequisite when compiling learning devices that incorporated TPACK (Yildiz and Arpaci, 2024). Teachers experienced obstacles when compiling teaching materials when the understanding of mathematics content, education, and technology incorporation in mathematics learning was less than optimal (Cheng et al., 2024; Ibrahim et al., 2024; Kholid et al., 2023; Koceski et al., 2025; Sevimli and Ünal, 2022).

Some of the technologies used by mathematics teachers in learning devices included YouTube-assisted learning videos, online test applications assisted by Quizizz, Google Forms, Canva, hyperlinks, QR codes, and Microsoft Office Excel. The results of this study supported Sridana et al. (2025), who showed that teachers often use several applications when compiling teaching materials. Several previous studies also showed that numerous applications commonly used when compiling learning devices included YouTube videos, Quizizz (Yanuarto and Hastinasyah, 2022), Canva, dan QR code (Kuru Gönen and Zeybek, 2022; Rabu et al., 2019; Vuksanović et al., 2021). This is because the applications tend to be attractive and interactive, which entice students in learning mathematics, and the use of technology becomes a space for innovative mathematics learning (Ahmed and Zaneldin, 2020; Berrios Aguayo et al., 2025). The results recommended that TPACK-incorporated learning device compiled by teachers could be implemented in the context of mathematics learning in schools.

The analysis results showed the feasibility of learning devices that are, on average, in the high and medium categories, specifically in terms of language, presentation, and graphics, contrary to the essence of TPACK in learning devices. In essence, the ability of mathematics teachers tended to be more than average in presenting learning devices, both in terms of language and graphic display. The results of this study supported Mawarsari et al. (2022), who showed that the generation of millennial teachers tended to have the ability to compile attractive materials using various technology platforms. Several previous studies also explained that mathematics teachers in the 21st century tended to be creative in presenting teaching materials by incorporating various types of technology to attract students to learning mathematics and make education more valuable (Gunawan et al., 2025; Gunbas, 2020). This is because mathematics teachers in the current century already have good skills in operating various applications that help in compiling learning devices or generating attractive graphics (Akuom and Greenstein, 2022). Following the discussion, these results recommend that mathematics teachers should use various applications in compiling learning devices, specifically when generating graphics, allowing learning devices to become more attractive and interactive.

Based on the analysis results of learning device, four mathematical competencies concerning the targets of the device were obtained. The results showed that critical thinking was a target in learning device. This outcome supported Sri et al. (2017), who explained that critical thinking was a target in learning. The study also showed that RME optimized critical thinking skills during the analysis. The results of this study supported several previous studies, which showed critical thinking as a target in innovative learning, including being used as a main focus in developing mathematics education curriculum (Khusna et al., 2024; Monteleone et al., 2023; Sari and Juandi, 2023). This is because critical thinking is an important mathematical competency in learning. Critical thinking enables someone to think more analytically, objectively, and logically, allowing problems to become easier when solved (Putri et al., 2025). In addition, the target formed open-mindedness in a person by using various perspectives, allowing individuals to become skilled and wiser when solving problems (Wang and Abdullah, 2024).

This study showed that the second target in learning devices compiled by mathematics teachers was creativity. The results followed Samritin et al. (2024), who explained that creativity should be a targeted competency in mathematics learning. Moreover, this analysis also supported several previous studies, signifying that creativity in mathematics learning should be a focus for optimal outcomes in education (Ekayana et al., 2025; Wahyuningsih et al., 2025; Zainal et al., 2024). This is because with competency, a person can develop various strategies or ways to solve problems (Joklitschke et al., 2022). The ability to reflect creatively enables individuals to think out-of-the-box, leading to new ideas, strategies, or solutions when solving problems that produce innovation in learning (Susilawati et al., 2024).

The next competency shown by this study was mathematical communication skills. The results supported Adlina et al. (2024), who explained that this competency should be a target in learning mathematics. Several previous studies also showed that mathematical communication skills were quite important and should be a competency developed in Education (Ardianti et al., 2021; Noor and Agoestanto, 2023). This is because mathematical communication skills help individuals when conveying ideas, allowing others to accept the thoughts more easily (Ferine et al., 2021). A person with good communication skills tends to provide better opinions to others, such as persuasion from teachers to students.

The subsequent result during the process of the analysis was collaboration competency. These findings supported García-Rico et al. (2021), who explained that mathematics learning should improve the collaboration skills of students. Similar conclusions were drawn in previous studies, signifying the importance of incorporating collaboration into mathematics education (Felmer, 2023; Siller and Ahmad, 2024). This is because collaboration is an important 21st century skill, enabling students to solve problems effectively, build strong network, and compensate for personal limitations by leveraging strength of others (De Paula et al., 2024). These results recommend that critical, creative, communicative, and collaborative thinking should be continuously optimized to improve the general quality of mathematics learning. This is intended to ensure that the process and results of mathematics learning are developed optimally.

The incorporation of TPACK into learning devices represented a form of innovation in learning. The innovation could also be developed by incorporating artificial intelligence (AI) into learning devices. This combination aims to ensure that learning devices created by mathematics teachers keep up with technological developments quickly and accurately. The incorporation of AI can overcome various obstacles that arise in student-centered learning. For example, time allocation is often long during student-centered learning (Isnawan et al., 2024), as it runs out when solving problems. Through the presence of AI, teachers can ask students to get help solving problems, allowing the allocation of learning time to be sufficient according to the previously determined schedule.

CONCLUSION

In conclusion, several results were shown in this study based on the previous description. Mathematics teachers were not able to optimally incorporate TPACK into learning devices. However, this study proved that the criteria for mathematics learning devices compiled by teachers were medium and low. The feasibility of mathematics learning devices compiled was categorized as high and medium. This was because the graphic display, presentation, and language used in learning devices were good. During the analysis, four competencies that focus on the target in learning devices compiled by mathematics teachers included critical thinking, creativity, communication, and collaboration. These four skills were competencies that were needed by individuals in the 21st century.

This study recommends several analysis activities for exploration in the future. First, learning devices compiled by mathematics teachers in this study should be implemented in the context of real mathematics learning in schools. Second, mathematics teachers should use various applications in compiling learning devices, specifically when making a presentation. This would allow learning devices to become more attractive and interactive. Third, critical, creative, communicative, and collaborative thinking skills should continue to be optimized, allowing optimal development concerning the quality of mathematics learning.

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