Effectiveness of TPACK-Based Multimodal Digital Teaching Materials for Mathematical Critical Thinking Ability

Arie Anang Setyo*, Sarson W. Pomalato, Evi P. Hulukati, Tedy Machmud, and Novianty Djafri

***Abstract*—Technological Pedagogical Content Knowledge (TPACK)-based multimodal digital teaching materials need to be developed to maximize the implementation of learning in the era of technological and digital advances. This study is a pre-experimental one-group pretest-posttest design to analyze the effectiveness of learning by utilizing multimodal digital teaching materials for TPACK-based analytical geometry courses to improve mathematics critical thinking skills of fourth-semester students. The students were from the mathematics education study program at Universitas Muhammadiyah Sorong. Furthermore, the instrument used in collecting research data is a mathematical critical thinking skills test. The research data were analyzed with descriptive statistics and N-Gain. The results showed that implementing learning using multimodal digital teaching materials for analytical geometry courses with TPACK-based was quite effective. It increased mathematical critical thinking skills by 2.24 (56.11%), and the average N-Gain value was 0.62 (62%) which was included in the medium category.**

***Index Terms*—Analytic geometry, mathematical critical thinking skills, multimodal digital teaching materials, Technological Pedagogical Content Knowledge (TPACK)**

I. Introduction

The educators of the 21st century must be able to integrate technological advances and the digital era to the fullest in the implementation of learning [1] while still carrying out the learning process to maximize the improvement of mathematical critical thinking skills [2, 3]. Critical thinking skills are fundamental abilities to be developed in mathematics learning. They are one of the 21st-century skills that will make students able to solve everyday problems they face today and, in the future [4–8].

A major requirement in the learning process is establishing good communication between educators and students. It can be assisted by the use of multimodal digital teaching materials [9], which are prepared by maximizing technology, but still applying pedagogical advances and the needs of content or learning materials [3], which is called the Technological, Pedagogical, And Content Knowledge (TPACK) framework. Such ability must be possessed by 21st-century educators [10].

Furthermore, teaching materials can be interpreted as a collection of materials that contain the competence of learning objectives and determine the success of learning, playing an essential role in the process and achievement of learning objectives [8, 11]. Teaching materials are also interpreted as an essential component in learning, including knowledge, skills, and attitudes that must be mastered according to the objectives set in the curriculum [12]. While multimodal is the process of communicating using only one semiotic source, it can be oral, written, text, and others [9]. Multimodal can also be interpreted as an interactive process that uses text to convey information and contains info graphics, images, or other means that help the learning process [13].

Multimodal digital teaching materials can be interpreted as a set of teaching materials presented in digital or web-based form by maximizing text, images, audio, video, dialectics (questions and answers), evaluation, reflection, and internet links are presented interactively to maximize the learning process and results [14, 15].

TPACK is an acronym for Technology Pedagogy and Content Knowledge, which is a framework that places a complex and mutually influential role between three components of the learning environment such as content or material, pedagogy, and technology [16]. TPACK describes the knowledge needed to maximize the learning environment with the interaction between technology and pedagogy to deliver content or material [17, 18]. The study related to TPACK should be oriented towards providing teachers with the knowledge needed to use and utilize technology effectively to improve the learning process [19] to be able to implement digital learning by integrating TPACK [20].

Multimodal digital teaching materials TPACK-based can be interpreted as a set of materials arranged in digital form by maximizing text, images, audio, video, dialectics (questions and answers), evaluation, and reflection, as well as internet links that are presented interactively with the help of knowledge related to technology and pedagogy as well as relevant content or knowledge material.

Critical thinking skills are one of the four skills that need to be taught in 21st-century learning [21], knowledge and skills that are the primary needs in the rapidly advancing and changing world [22]. Critical thinking skills can also help to reflect on making the right decision from the results of a good and correct conclusion [23, 24]. Critical thinking skills can be the ability to think logically and reflectively, focusing on a decision that is already believed. In line with the explanation about critical thinking skills, it can be concluded that critical thinking skills are one of the 21st-century skills that are very important to master. So that students can think logically and reflect on concluding information properly and correctly so that they can make the right decision.

The results of the study mentioned that multimodal digital teaching materials or e-learning are effective in improving student learning processes and outcomes and can increase the

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creativity of lecturers in making learning media [14, 15, 25]. TPACK describes the knowledge needed to maximize the learning environment with the interaction between technology and pedagogy to deliver content or material. Also, TPACK and digital multimodal are oriented towards providing the knowledge needed for teachers to be able to use and utilize technology effectively in an effort to improve the learning process. Thus, both teachers and prospective teachers are also critical to understand various knowledge and paradigm shifts and critical perspectives related to the development of innovative learning processes oriented to TPACK [2, 25, 26]. Teachers and prospective teachers are also essential to understand and be able to implement TPACK in innovative learning [27].

A review of relevant study revealed that few studies develop multimodal digital teaching materials for analytical geometry courses TPACK-based for mathematical critical thinking skills and measures its effectiveness. The novelty of this research lies in developing multimodal teaching materials in analytical geometry courses with TPACK-based for mathematical critical thinking skills.

TPACK-based multimodal digital teaching materials need to be developed to maximize the implementation of learning in the era of technological and digital advances. This study aimed to analyze the effectiveness of learning by utilizing multimodal digital teaching materials for analytical geometry courses based on TPACK to improve students' mathematical critical thinking skills.

This study conducted because of mathematical critical thinking skills of students from the mathematics education study program at Universitas Muhammadiyah Sorong was low. This is showed by the pretest results in the analytical geometry course showed that the average student's critical thinking skills were 0.33 (8.42%) in the significantly less critical category. The results of interviews with representative lecturers and students revealed that students had low critical thinking skills. It is partly due to the need for more availability of teaching materials. Teaching materials commonly used are still in the form of pdf, power points, and printed books that are only text and images. Teaching materials available and used in learning must maximize yet the use of multimodal and TPACK-based and increased mathematical critical thinking skills. Thus, it is important to develop multimodal digital teaching materials for TPACK-based analytical geometry courses for mathematical critical thinking skills and test their effectiveness.

Thus, this study aimed to determine the effectiveness of multimodal teaching materials for analytical geometry courses TPACK-based for improving mathematical critical thinking skills of students of the mathematics education study program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Sorong.

II. Literature Review

21st-century skills are a necessity that all prospective teacher students must master to prepare their students to master these skills. One of the 21st-century skills is critical thinking skills such Basri and Purwanto *et al.* [21], which is a skill that can prepare students to face and solve various problems they face both now and in the future as Walters and Greene *et al.* [4] in preparing students to face the rapid advancement of science and technology. Further, Kriel [22] adds by carrying out a logical and reflective thinking process, and focusing on a decision that is believed [28, 29].

Critical thinking skills can be improved by implementing a learning process oriented towards improving critical thinking skills and maximizing the use of technology, pedagogy, and material content by critical thinking skills. It is lines with Zayyadi and Nusantara *et al.* [3] and Sarifudin and Abidi *et al.* [9]. The learning process will be more meaningful if educators can design teaching materials that can accommodate various modalities of learning in the form of text, audio, video, images, and material links and are interactive or multimodal as Hadianto and Damaianti [13].

Educators need to make various innovations through the development of multimodal digital teaching materials with TPACK orientation to improve student's critical thinking skills. Its lines with Setyo and Layn [14] and Masfingatin and Murtafiah [15], so that prospective teachers will have the knowledge and critical thinking skills in developing teaching materials that can be utilized in the learning process [25, 26].

III. Method

This study's stages consisted of developing multimodal digital teaching materials for analytical geometry courses TPACK-based. Then, conducting a trial for measuring students' critical thinking skills through a pretest, implementation of learning for six meetings by utilizing multimodal digital teaching materials for analytical geometry courses TPACK-based, and ended with the implementation of the posttest.

The subjects in this study were fourth-semester students of the mathematics education study program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Sorong, the academic year 2021/2022, totaling 15 people. The study's sample was students who contracted the analytical geometry course. The variable measured in the study was mathematical critical thinking skills.

The instrument used in the study was a critical thinking skills test instrument for collecting data on students' mathematical critical thinking skills. Before being used, the instrument was validated by two experts. Data collection techniques are done through the initial test (pretest) and the final test (posttest).

The data were analyzed descriptively, and N-Gain analysis with the formula [30].

$$\text{N-Gain} = \frac{\text{Skor Posttest} - \text{Skor Pretest}}{\text{Skor Maksimum} - \text{Skor Pretes}}$$

The results of the N-Gain data analysis are categorized according to the category [31] stated in Table I.

TABLE I: N-gain Score Category

Gain Score	Category
$G < 0.3$	Low
$0.3 \leq G \leq 0.7$	Middle
$G \geq 0.7$	High

To measure effectiveness, categories are used according to Table II.

TABLE II: EFFECTIVENESS OF N-GAIN SCORE [32]

N-Gain Score (%)	Category
< 40	Ineffective
40–55	Less Effective
56–75	Quite Effective
>76	Effective

Data on the results of students' mathematical critical thinking skills collected based on indicators of critical thinking skills, as follow: 1) Skills in observing and identifying problems, 2) Skills in analyzing strategies and techniques as alternative solutions. 3) Skills in evaluating and solving problems [33–35]. The data collected were analyzed with the critical thinking skills categories presented in Table III.

TABLE III: CATEGORY OF MATHEMATICAL CRITICAL THINKING SKILLS [6]

The Critical Thinking Indicator Achievement (%)	Category
81–100	Highly Critical
61–80	Critical
41–60	Quite Critical
21–40	Less Critical
0–20	Poorly Critical

IV. FINDINGS AND DISCUSSION

Initial data collection of students' critical thinking skills through critical thinking skills pretest was carried out before learning by utilizing multimodal digital teaching materials based on TPACK. The pretest questions were in the form of descriptions totaling six questions, with material namely the cartesian coordinate system, straight line equations, and circular equations. The pretest was conducted for 90 minutes, with 15 students participating. The results of the pretest data analysis are presented in Table IV.

TABLE IV: PRETEST DATA ANALYSIS RESULTS

Indicator	Average	Percentage (%)	Category
1	0.40	10.00	Poorly critical
2	0.47	11.67	Poorly critical
3	0.28	6.94	Poorly critical
Average	0.38	9.54	Poorly critical

Table IV shows that indicators of critical thinking skills related to skills in observing and identifying problems have an average score of 0.40 (10.00%) with a significantly less critical category. While the lowest average score on indicator 3 (Able to solve problems) with an average score of 0.28 (6.94%), and indicators related to skills in analyzing strategies and techniques as alternative solutions at an average score of 0.47 (11.67%), with the total average of the three indicators being 0.38 (9.54%) with a significantly less critical category. Students' soft skills in solving pretest questions are because they are not used to solving questions related to necessary thinking skills. It can be seen in the non-answering of pretest questions by more than 80% of research subjects.

After the pretest, the learning process was carried out for six meetings with a description: The first and second meetings discussed cartesian coordinates, the third and fourth meetings discussed straight-line equations, and the fifth and sixth meetings discussed circular equations. In this study, multimodal digital teaching materials TPACK-based are teaching materials that maximize text, images, audio, video or YouTube, material links, and learning technology in the form of GeoGebra facilities and web-based digital teaching material makers that can be accessed at https://heyzine.com/. An illustration of the teaching materials used can be seen in Fig. 1.

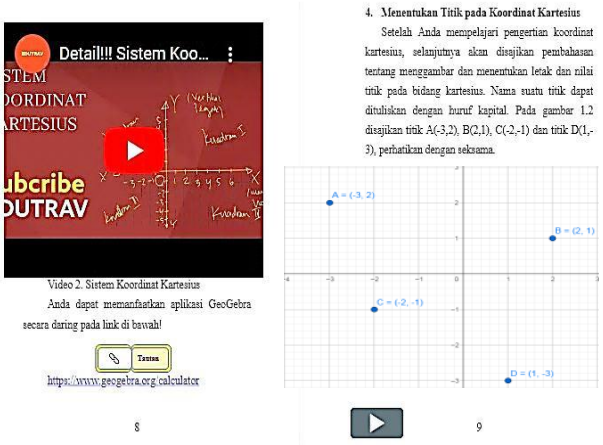

Fig. 1. Illustration of TPACK-based multimodal digital teaching materials. https://www.geogebra.org/calculator

In Fig. 1, it can be analyzed that the teaching materials used have utilized multimodal in the form of text, images, audio, YouTube, material links, or technology. After the implementation of learning, a final test or posttest was conducted. The results of the posttest data analysis are presented in Table V.

TABLE V: THE RESULTS OF POSTTEST DATA ANALYSIS

Indicator	Average	Percentage (%)	Category
1	2.06	51.47	Quite Critical
2	2.56	63.97	Critical
3	2.28	57.11	Quite Critical
Average	2.30	57.52	Quite Critical

The posttest results are presented in Table V. It can be examined that, from a maximum score of 4, critical thinking skills indicators 1 and 2 have an average value of 2.06 (51.47%) and 2.56 (63.97%), respectively, with a reasonably critical category, while indicators 3 and the total average is 2.38 (57.11%) and 2.30 (57.52%) respectively also in the reasonably critical category.

In measuring the improvement or effectiveness of multimodal digital teaching materials for analytical geometry courses TPACK-based for mathematical critical thinking skills, the results of the analysis of the improvement of critical thinking skills during the pretest and posttest are presented in Table VI.

Based on the table above, Table VI shows that all indicators of critical thinking skills have increased in each indicator, with the highest score increase of 2.24 located in indicator 2, with a total average increase score of 2.24 (56.11%). The results of the N-Gain value review on each indicator are in the score range of 0.3 and 0.7 or the moderate category, with an average N-Gain value of 0.62 (62%) with a

moderate category, when compared to the effectiveness criteria based on the N-Gain value, it meets the category quite effective. Implementing learning by utilizing multimodal digital teaching materials for TPACK-based analytical geometry courses is quite effective in improving mathematical critical thinking skills, with an average increase of 2.25 (56.25%) and an average N-Gain value of 62%.

TABLE VI: COMPARISON OF CRITICAL THINKING SKILLS AND N-GAIN SCORES

Description	Critical Thinking Indicators			Average	Percentage (%)	Category
	1	2	3			
Pretest	0.40	0.47	0.28	0.38	9.50	Poorly Critical
Posttest	2.78	2.71	2.39	2.63	65.75	Quite Critical
Improvement	2.38	2.24	2.11	2.25	56.25	
N-Gain	0.66	0.64	0.57	0.62	62	Quite Effective

The results of this study are in line with the results of research [14, 15, 22], which state that multimodal digital teaching materials or e-learning are effective in improving the learning process and results and following the results of research [2, 25], which state that it is very important for teachers and prospective teachers to understand various knowledge and paradigm shifts and critical perspectives related to the development of innovative learning processes oriented to TPACK. The results are also relevant to research conducted by Ismaeel and Mulhim [36] which states that it is very important for teachers or prospective teachers to develop TPACK-related skills through a combination of traditional and digital or online learning.

V. CONCLUSION AND FUTURE DIRECTIONS

The results of the study concluded that implementing learning by utilizing multimodal digital teaching materials for analytical geometry courses TPACK-based is quite effective in improving students of mathematics education study programs' critical thinking skills. Increased mathematical critical thinking skills by 2.24 (56.11%) with an N-Gain value of 0.62 (62%) in the moderate category. Multimodal teaching materials developed and tested in the study consisted of text, images, audio, video, material links, and web based.

Then, the researcher suggests for further research to be able to utilize the use of TPACK-based to improve student critical thinking in other courses. The author gives suggestions related to the implementation of this study that learning and teaching materials should be developed following the context and era of the students who learn. For generation Z students, teaching materials used in learning should maximize multimodal (in the form of text, images, audio, video or YouTube, material links, and are interactive or web-based) by utilizing technology, pedagogy, And Content Knowledge (TPACK), and oriented towards improving students' mathematical critical thinking skills.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Arie conducted the study by developing the instruments, collecting data, analysis, and write papers. Others can be written to provide scientific input and suggestions in this study, data analysis and article writing and article improvement. All authors have approved the final version.

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