Improvement of Mathematical Critical Thinking Skills through Project-Based Mathematics Mobile Learning Implementation with TPACK Framework

Kuswari Hernawati[1*]
[1] Mathematics Education Departement, Yogyakarta State University, Yogyakarta, Indonesia

kuswari@uny.ac.id

Abstract
Critical thinking is one of the 21st century skills that students are required to master to face the challenges of the 21st century. In mathematics learning, mathematical critical thinking skills are needed for students to be able to solve problems found in everyday life through mathematics. This study aimed to provide empirical evidence and examine learning using the project-based math mobile learning (Pj-B Mob Math) with the TPACK framework can improve students' mathematical critical thinking skills. Researchers collected data using test techniques (pretest and posttest), which were obtained from the results of tests conducted by 214 students in the 12th grade of high school. It was proven that project-based math mobile learning with the TPACK framework was able to improve the mathematical critical thinking skills of high school students.
Keywords: Project-base, mobile, mathematics, critical thinking, TPACK

1. INTRODUCTION

The 21st century is an era of massive and rapid change. Various sectors of life are moving rapidly and full of challenges. According to [1], 21st century society is faced with economic conditions directed by innovation and knowledge, intense competition in business and innovation, various possibilities and risks, complex problems in various fields, and the need for collaboration and social networking. All of these circumstances present new challenges for education. Finding ways to create successful citizens who are capable of adapting to all changes and circumstances in the 21st century is a challenge for current education system. The current system must be able to provide the abilities needed to overcome all the problems that are developing in society. As a result, 21st century skills are essential to be taught to students.

According to Kay & Greenhill (2010: 46), some of the 21st century skills that students must acquire is critical thinking and decision making. This was also consistent with the opinion of [2] who defined seven core abilities in 21st century skills, i.e. technical skills, processing information, communication, collaboration, creativity, critical thinking and problem solving. Based on Permendikbud No. 37/2018, critical thinking is included as one of the lesson outputs in Indonesia. Based on these statements, it can be concluded that critical thinking is one of the important abilities that must be provided to students.

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[3] defined critical thinking as active, persistent, and careful consideration of certain beliefs or knowledge by including supporting evidence that would lead to the right conclusion. Norris & Ennis (1989) stated that critical thinking is logical, reflective thinking that focuses on making decisions regarding what to do. Therefore, it can be concluded that critical thinking is a logical, reflective and rational way of thinking (using relevant evidence) to decide what to believe or what to do. [4] revealed that high school students still have a low level of critical thinking when faced with problems. Similar results were obtained by [5] which revealed that the critical thinking of high school students who were the research subjects was in the low category.

Critical thinking requires some basic thinking skills that support it. Some of these thinking skills include the ability to recognize problems, find meaningful solutions to solve problems, gather useful information, recognize implied values and assumptions, interpret data, assess evidence and various evaluations, be able to recognize logical relationships contained in propositions, make appropriate conclusions and generalizations, provide assessments of various phenomena in everyday life [6] [7] has proposed a framework related to critical thinking. According to him, critical thinking is a 3-step thinking process, consisted of clarity, conclusion, and decision. Clarity means understanding the problem and its purpose. Conclusion means the process of thinking towards a solution to be carried out or applied. Decision means deciding the action for each conclusion obtained.

Critical thinking has been a problem for high school students in Indonesia. One way to train this way of thinking is through learning. Permendikbud No. 65 Tahun 2013 mandates that the learning process in educational units should be conducted in an interactive, inspiring, fun, challenging manner, motivating students to actively participate, as well as providing sufficient space for ideas, creativity, and independence in accordance with the talents, interests, and physical and psychological development of students. Teachers are required to have content (subject) knowledge, pedagogical (how to adapt content to students), general pedagogical (e.g. classroom management), curricular, contextual (teaching context) and process knowledge (learning skills, observation skills, etc.), cooperation skills, flexibility and the ability to connect between students [8]. PjBL with TPACK framework can be one of the models that teachers can utilize to facilitate students in learning.

PjBL, stands for Project-Based Learning, is a learning model where the learning context is presented through authentic questions and real-life problems [9]. Various studies have proven that PjBL has a positive influence on critical thinking. [10]. revealed that PjBL has an influence on critical thinking. The results of research by [11] explained that PjBL as an active learning has the potential to foster students' critical thinking in the classroom. On the other hand, PjBL can improve students' critical thinking [12]. The empirical evidence explains that PjBL can improve students' critical thinking. PjBL as a learning model can be combined with other learning paradigms, one of which is TPACK.

TPACK (Technological Pedagogical Content Knowledge) is the heart of good teaching and is consisted of three components: content, pedagogy, and technology

[13] TPACK is considered effective to be applied in 21st century learning due to the urgency of technology implementation in education. TPACK could facilitate teachers and students in integrating technology in learning as explained by [13]. This is reinforced by the opinion of [14] who revealed that teachers in all disciplines must learn to design and develop technology that can foster student success in today's modern learning environment.

TPACK is not something new in the world of education. Many researchers have tried to analyze its benefits and provide empirical evidence. [15] through their research revealed that media-based TPACK learning can be used to train students' critical thinking. Similar results are present in [16] which explains that the PBL model with TPACK is effective in improving the critical thinking of high school students. Based on these two results, it can be concluded that TPACK is one of the paradigms that can be used to improve students' critical thinking.

This study aimed to examine the effect of PjBL with TPACK framework in improving students' critical thinking along with empirical evidence. The combination of these two things is a new thing in social-humanities research. Based on previous literature review, the researcher assumed that the combination of PjBL with TPACK framework could improve students' critical thinking skills. The researcher tried to organize a learning setting with PjBL integrated with TPACK in the classroom. The researcher applied mobile learning using a website that had been developed and validated to achieve the objectives. Mobile learning is a technique that uses wireless and mobile technology for learning that allows students to combine their learning experiences in a collaborative environment [17]. This research may be useful as a basis for similar research, proposing an alternative model that teachers can use to improve students' critical thinking in an interactive and up-to-date way, as well as providing empirical evidence on the effects of PjBL with TPACK framework to improve students' critical thinking.

2. METHODS

The research subjects were 12th grade high school students from 6 different classes. The researcher conducted the experiment for a total of 6 meetings in each class. A classroom setting that integrates students with technology was created. The researcher implemented mobile learning in a self-designed learning website that has been validated. Critical thinking data was obtained through written tests given to students before (pretest) and after treatment (posttest).

The written test used was a description test on opportunity material for grade 12 high school. After obtaining the data, R-studio was used to analyze the data. T test for two dependent samples was utilized to statistically analyze the data. Each class was statistically tested and conclusions were drawn. PjBL with TPACK framework is considered to improve students' critical thinking if the p-value is less than $\alpha = 5\%$. The t test has assumptions that must be met first, namely the assumption of univariate normality. The assumption of univariate normality was tested using Shapiro-Wilk.

Data is normally distributed (fulfills the assumption of univariate normality) if the p-value is more than $\alpha = 5\%$

3. RESULTS AND DISCUSSION

The project-based math mobile learning with TPACK framework learning is a model learning in which students learn constructively. It uses project activities by using mobile devices, especially smartphones, in learning activities and project creation. Trial took place during math learning in grade 12. Although this learning model is designed to fully support online learning, it is very possible in practice if it is used with blended learning. Project-based math mobile learning uses the principles of Dewey with a "learning by doing" approach. Therefore, with the TPACK framework learning, project-based math mobile learning offers opportunities for the development of learning methods, including: : a) renewal of learning (curriculum enrichment) by integrating research results, b) active participation of students in the implementation of learning, c) learning by using research instruments, and d) development of an inclusive research context, enrichment of learning resources, reference books and internet facilities [18].

The support system in project-based math mobile learning with the TPACK framework in the form of (a) Mathematics learning tools in the form of lesson plans, teaching materials for rules of enumeration; (b) LMS Pj-B MobMath is built with Moodle LMS; (c) Mathematical Critical thinking assessment instrument; and (c) Student Worksheet. Before learning, a pretest is carried out, to see the students' initial abilities. Furthermore, in the learning process, students follow the learning steps as presented in the student worksheet. Students are guided to discover mathematical concepts on their own with mathematical critical thinking stages. At the end of the lesson, a posttest was carried out to see the students' understanding of the learning material and mathematical critical thinking skill, that is, mental activities in the field of mathematics that are carried out using steps in the scientific method, to achieve four skills, namely interpretation, analysis, evaluation, and inference. The material taken in this study is Permutation and combination.

The statistic test used in this study was the t-test on two dependent samples. Each class was analyzed individually and inferred based on the p-value. PjBL with TPACK framework is proven to improve students' critical thinking skills if the p-value is less than $\alpha = 5\%$. The assumption of univariate normality must be met first before continuing the analysis with the t-test. The assumption of univariate normality was tested with Shapiro-Wilk. The results of the univariate normality assumption test for each research class sample are presented in Table 1.

Table 1. Results of the normality assumption test of the research sample

Class 1		Class 2		Class 3		Class 4		Class 5		Class 6	
SW	*p*-	SW	*p*-	SW	*p*-	SW	*p*-	SW	*p*-	SW	*p*-

	value		*value*		*value*		*value*		*value*		*value*
0.960	0.215	0.972	0.484	0.968	0.377	0.954	0.142	0.957	0.173	0.954	0.144

Table 1 shows that all classes were normally distributed. This is evident from the p-value of all samples which is more than α = 5%. The research data were univariate normally distributed, so the data analysis was continued to the t test. The t test aims to test statistically related to the average difference in repeated assessments of each sample. The difference in question is the difference between the post-test and pre-test scores. The significance of the t test results indicated an increase in students' critical thinking. The t-test results of each sample are presented in Table 2.

Table 2. T-test result

Class 1		Class 2		Class 3		Class 4		Class 5		Class 6	
t	*p-value*	t	*p-value*	t	*p-value*	t	*p-value*	t	*p-value*	t	*p-value*
19,838	2,2	28,827	2,2	74,269	2,2	62,798	2,2	24,689	2,2	43,795	2,2

All samples have a p-value that is less than α=5% as shown in Table 2. This indicates that the project-based mobile math learning with TPACK is statistically significant ($p<0.05$). Therefore, at the 95% confidence level, the learning is proven to be able to improve students' critical thinking in each research sample.

Project-based math mobile learning with TPACK is an alternative learning setting that can improve students' critical thinking skills. These results were in line with the research of [12] which revealed that PjBL that is multidisciplinary integrated can improve critical thinking. In addition, [19] explained that PjBL integrated with 4C is empirically proven to develop critical thinking skills. [20] stated that the PjBL model can train and improve students' critical thinking because the learning is centered on students, students are trained to try solving problems found in everyday life and students are fully given freedom in the learning process.

Mobile learning offers an interconnected learning environment for the development of critical thinking skills. Various technologies integrated in this learning environment provide opportunities for students to reflect on their work in the form of text, video, audio or other media that can lead to critical and creative thinking [21] [22], found that mobile learning with PjBL can improve critical thinking skills. The flexibility of technology can encourage passive students to be active in the classroom, therefore can train students' critical thinking in the classroom [23]. The researcher applied PjBL in a mobile learning environment that requires students to collaborate in groups to solve problems. Students experimented with cards, web and other media provided and recorded the results on worksheets that were connected directly to the class forum on the web. The researcher acted as a facilitator and validator of the process of finding solutions to the conclusions made by students.

The results of this study also confirmed various previous studies such as [15] and [16] [15] stated that teachers could train students' critical thinking by using

TPACK-based media learning. On the other hand, [16]explained that the TPACK-based PBL model is effective in improving high school students' critical thinking.

4. CONCLUSION

This study presents empirical evidence on the improvement of critical thinking skills through project-based math mobile learning with the TPACK framework. The findings proved that project-based math mobile learning with the TPACK framework was able to improve the critical thinking skills of high school students. This could be used as a reference for further research and as an alternative learning model for educational practitioners who aim to improve students' critical thinking in the classroom.

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