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TPACK Theoretical Correspondence with Learning Variables and Its Application Effectiveness in Learning

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ABSTRACT

The role of educational technology is to facilitate people to learn more efficiently to achieve optimal learning outcomes. One thing that can be done is to promote learning using learning media. However, this learning media will be effective with the right learning strategy. This study aimed to describe the correspondence of the TPACK framework with learning variables in educational technology in the digital era based on literature studies of the effectiveness of implementing the flipped classroom learning strategy assisted by virtual laboratory media on understanding mathematical concepts through pre-experimental studies. The subjects of this study were researchers, teachers, and 8th-grade students of SMPN 5 Abiansemal-Badung-Bali in the even semester of the academic year 2022/2023. The data collection instrument was a test of understanding mathematical concepts. Literature study data analysis was conducted by searching relevant theories and collecting articles, data reduction, discussion, and conclusions. The pre-experimental study was carried out by calculating the value of the students' pre-test and post-test gain scores for understanding mathematical concepts. There is a description of the correspondence of the TPACK framework with learning variables in educational technology: Technology elements correspond to condition variables; Paedagogy corresponds to method; and content knowledge corresponds to the outcome variables. The gain score of understanding students' mathematical concepts by applying the flipped classroom assisted by the virtual laboratory obtained 28% of students achieving the high criteria, 48% attaining moderate criteria, and 24% receiving low criteria. Thus, the flipped

classroom learning strategy assisted by virtual laboratory media effectively increases students' understanding of mathematical concepts.

Keywords
Flipp Classroom
Learning Strategy
TPACK
Virtual Laboratory

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Introduction

Entering the Era of the Industrial Revolution 4.0, the life skills needed to survive include Complex problem solving, Critical thinking, Creativity, Coordinating with others, Judgment and decision making [1]-[3]. These life skills have become the focus of organizing education in this digital era. These life skills can be started by providing education oriented towards higher-order thinking skills (HOTS), such as skills to analyze, evaluate, and create [4]. Implementing effective education must be connected to the role of technology and information.

The rapid advancement of digital technology has implications for various aspects of life, including education. The development of technology and information, especially mobile phones and the internet, has resulted in changes in learning without the boundaries of space and time [5]. The internet allows people to connect with various parties without meeting face-to-face in real time. Integrating technology in achieving optimal learning outcomes is urgent in implementing 21st-century education, which is also synonymous with the digital era.

Since learning has used online mode in the era of the COVID-19 pandemic, the process of using ICT in education has seemed "forced and accelerated". All elements of education, starting from educators, students, parents, and society, must be prepared to face this situation. All must be able to move quickly so that learning loss does not occur. Learning in online mode requires students to be able to manage learning independently, namely Self Regulated Learning. If students can do it with time and discipline, have high motivation to learn, and overcome existing obstacles, they can achieve learning outcomes effectively and efficiently. However, if students feel burdened and experience many obstacles in carrying it out, the learning outcomes to be completed will not be effective. Even though the COVID-19 pandemic has ended, it is difficult to abandon implementing online learning. The quality of this online mode should continue to be improved by seeking various efforts to overcome weaknesses in its implementation. This is one of the most essential tasks in critical technoeducational technology, which facilitates effectively and efficiently and has appeal [6]. One of the efforts

made through this research is integrating the TPACK framework in learning by paying attention to learning variables in designing learning activities. As an implementation, a pre-experimental analysis was carried out on the impact of a flipped classroom learning strategy assisted by virtual laboratory media on students' understanding of mathematical concepts.

Literature Review

A. The TPACK Concept

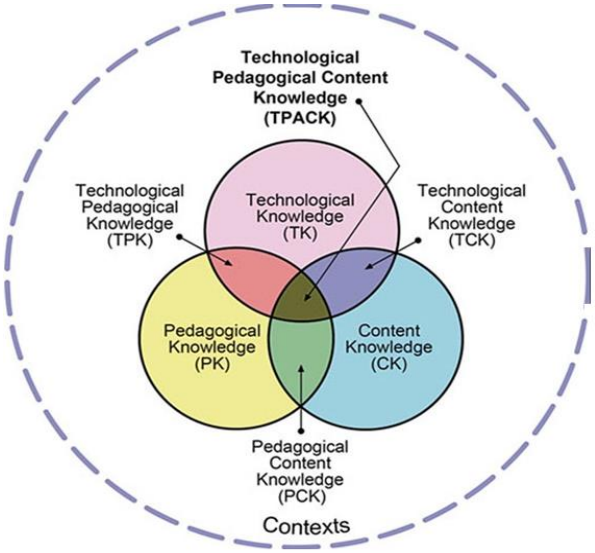
TPACK (Technological Pedagogical and Content Knowledge) is the application of a learning system that prioritizes the application of certain technologies and applications in learning. TPACK is a framework that identifies knowledge and how to convey it effectively and efficiently through technology integration. The basic concept of TPACK was first introduced by Mishra and Koehler in 2006. They discussed TPACK as an educator/designer framework for integrating technology into learning. The TPACK concept emerged in educational technology based on the pedagogy content knowledge (PCK) model pioneered by Ref. [7].

The basic concept of TPACK emphasizes the relationship between subject matter, technology and pedagogy [8]-[9]. The interaction between these three components has the power and appeal to foster active learning focused on students. In other words, there is a shift in learning centred on educators and shifts to learning centred on students. TPACK emphasizes the relationships between technology, curriculum content and pedagogical approaches that intersect with one another, namely between material (C), pedagogy (P) and technology (T), which are influential in the learning context. See Fig. 1. TPACK involves seven knowledge domains that are interrelated with one another, namely:

- Content Knowledge (CK), namely knowledge about the subject matter to be studied. The curriculum contains this material, including knowledge of concepts, theories, ideas, frameworks, and methods supplemented by scientific methods and their application in everyday life.
- Pedagogical Knowledge (PK), which describes in-depth knowledge related to teaching and learning theory and practice, which includes lesson planning; implementation of learning (including the selection of learning models, approaches, strategies, learning methods, and others); and learning assessment. PK requires an understanding of cognitive, affective, and psychomotor aspects, the development of learning theories, and how these theories can be applied in the learning process [8]. Some examples are using constructivism theory, cybernetic theory, scientific approach, discovery learning, problem-based learning, guided inquiry, question and answer, discussion, presentation, observation, or practicum.
- Technological Knowledge (TK) is the basics of technology that can support learning. For example, software, animation programs, internet access, molecular models, virtual laboratories, etc. Therefore, the ability of educators is needed in mastering information

processing and the ability to communicate through ICT in learning. Examples: Google Drive, OneNote, ChemDraw, Chemsketch, Prezzi Edmodo, YouTube, Ulead, Windows movie maker, avidemux, jmol, hyperchem, chemtool, bkchem, lectora, moodle, dokeos, ATutor, internet, laptop, LCD, video, or power point.

- Pedagogical Content Knowledge (PCK), which includes interactions and intersections between pedagogy (P) and content (C) in Shulman [8]. So, PCK is a learning process related to the subject matter being studied and applying learning methods to help students achieve learning outcomes effectively and efficiently. Example: Discovery Learning and constructivism as a learning model for flat-sided shapes.



Source: http://TPACK.org

Fig. 1. TPACK domains

- Technology and Content Knowledge (TCK), namely knowledge about technology and knowledge of the field of study or learning materials.
- Technological Pedagogical Knowledge (TPK), namely knowledge of technology and knowledge of learning processes and strategies.
- Technological, Pedagogical, Content Knowledge (TPCK), namely a series of learning where the ability to master technology is integrated and inseparable from one another. Example: Using a virtual laboratory with a flipped classroom learning strategy to increase understanding of concepts. With the help of technology, students can explore concepts and develop their ideas. Choosing the proper learning method directs students to have an experience-based understanding and can apply the material learned to solve problems in everyday life.

B. Learning Variables and Learning Design Theory

Learning is an effort to facilitate students to learn. Two theories underlie learning design, namely descriptive theory and prescriptive theory. Three learning variables affect learning design according to Ref. [6], namely, learning conditions, learning methods, and learning outcomes. Learning conditions are factors that influence the effect of the method in improving learning outcomes that cannot be manipulated. Learning methods are different ways to achieve other learning goals under other conditions. Learning methods can be influenced by learning designers. Learning outcomes include all effects that can be used as indicators of the value of using learning methods under different learning conditions. Learning outcomes can be in the form of natural results (actual outcomes) and desired outcomes. Actual outcomes are the tangible results of using a method under certain conditions. Expected outcomes are the goals to be completed, which affect the decisions of learning designers in choosing learning methods.

Descriptive theory is a learning theory that aims to explain the learning process. Descriptive learning theory places the condition variables and learning methods as given and places learning outcomes as observed variables. In other words, conditions and learning methods are independent variables, and learning outcomes are dependent variables. Descriptive theory is goal-free, meaning that the observed variable is learning outcomes due to the interaction between methods and conditions.

Prescriptive theory is a learning theory that places learning conditions and outcomes as given, and optimal methods are defined as observed variables [10]. Thus, the needs and learning outcomes are independent variables, while the learning method is the dependent/bound variable. Prescriptive theory is goal-oriented, meaning that the variables observed in developing a prescriptive learning theory are optimal for achieving goals.

It can be concluded that the difference between prescriptive theory and descriptive theory can be observed from the position of the theory. Prescriptive theory, the main goal of learning theory, is to determine the optimal learning method, while descriptive theory, the primary purpose of learning, is to explain the learning process. Descriptive theory only pays attention to the relationship between the variables of learning outcomes. Prescriptive theory, however, focuses on how a person influences others so that the learning process can occur. In other words, prescriptive theory deals with efforts to control the variables specified in learning theory to make it easier for people to learn. The theoretical differences above ultimately lead to consequences for differences in descriptive theory and perspective theory. The proposition for descriptive theory uses the logical structure "If.....then.....", while the prescriptive theory uses the system "so....do it..... " [11] in Ref. [12].

Examples of descriptive learning theory. If the subject matter is facilitated by technology.....(conditions) using learning models.....(methods), then learning outcomes will

increase (results)—examples of prescriptive learning theory. To improve learning outcomes (results), facilitate subject matter with technology.....(conditions), use models.....(methods).

Material and Methods

This research method uses a literature review and pre-experimental methods. The stages of literature study research start from searching for relevant theories and collecting articles, data reduction, discussion, and conclusions. Research data sources are in theories and journal articles in the last five years (2018-2023).

To strengthen the theory of integrating TPACK in learning according to the learning design variables, research was conducted on applying virtual laboratory learning media with the flipped classroom learning strategy to see its impact on students' understanding of mathematical concepts. A pre-experimental study was conducted at SMPN 5 Abiansemal, Badung-Bali, to obtain results from the effects of implementing the flipped classroom learning strategy assisted by virtual laboratory media on students' understanding of mathematical concepts. This study was conducted through the implementation of TPACK in learning. The subjects of this study were one math teacher and 25 8th-grade students at SMP Negeri 5 Abiansemal in the even semester of the academic year 2022/2023. Data on understanding mathematical concepts was collected using a description test, with indicators of understanding concepts including the ability to restate a concept, distinguish examples and non-examples of a concept, classify objects according to specific characteristics, apply concepts or problem-solving algorithms, and associate material with its benefits in everyday life. The types of questions given are descriptions, which consist of five questions. The pretest is given before learning using the flipped classroom learning strategy assisted by virtual laboratory media, and the posttest is given after the learning is carried out.

The following formula calculates the concept understanding score for each learner.

$$\text{Score} = \frac{\text{total score}}{\text{maximum score}} \times 100\% \quad (1)$$

An analysis of students' conceptual understanding is carried out by calculating the N-Gain Score, which is obtained based on a comparison of pre-test and post-test scores through the following formula adapted from [13].

$$g = \frac{S_{Post} - S_{Pre}}{S_{Max} - S_{Pre}} \quad (2)$$

Remark:
g : The normalized gain score
SPost : Posttest score
SPre : Pretest score
SMax : Maximum Score

The N-Gain Score interval obtained is categorized in Table 1.

Table 1. Interval N-Gain Score

Score (g)	Category
(N-Gain)≥0,7	High
0,7>(N-Gain)≥0,3	Medium
(N-Gain)<0,3	Low

Results

A. TPACK Correspondence with Learning Variables

Based on the study of the TPACK framework and learning variables, a correspondence can be made between the two concepts. The post can be described in Fig. 2.

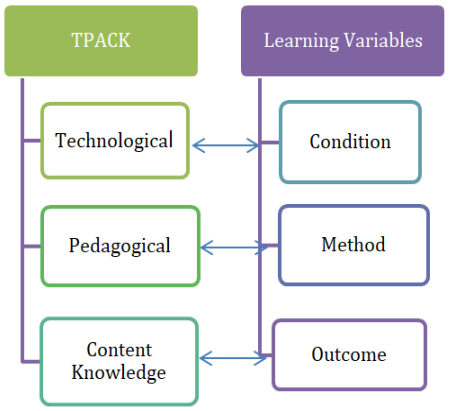


Fig. 2. TPACK Framework Correspondence with Learning Variables

The learning condition variable is closely related to the choice of technology to facilitate learning. The choice of technology is very closely related to the subject matter to be taught. With the help of technology, subject matter that is difficult or unimaginable to students can be assisted by developing media, for example, animated media, manipulative media, interactive media, gamification, Augmented reality, virtual reality, virtual laboratories, or others.

Learning conditions facilitated by technology, of course, will only be able to run effectively if applied in a relevant and appropriate way. The method used in the learning variable is included in the method variable. This method variable is an element of pedagogy in the TPACK framework. Thus, when applied to learning in the right ways, the technology that has been designed will be able to provide optimal results.

Learning outcome variables are learning aspects, including knowledge, skills, attitudes, and all the impacts to be achieved, both instructional and accompanying. When associated with the TPACK framework, it is included in the content/subject matter knowledge component. The results to be achieved in implementing learning are by the learning outcomes specified in the curriculum related to the material to be taught.

It can be concluded that the learning variables proposed by Reigeluth and the TPACK framework can be a one-to-one correspondence of how the learning design will be developed and adjusted to the position of the theory, whether the idea is descriptive or prescriptive. Thus, it will produce a learning design study, for the descriptive approach will tend to lead to experimental studies (quasi-experimental). In contrast, the prescriptive approach tends to lead to development studies.

B. The Impact of Implementing The Flipp Classroom Learning Strategy Assisted by Virtual Laboratory Media on Students' Understanding of Mathematical Concepts

The following research results implement the TPACK framework using the junior high school mathematics learning topic. The learning design uses descriptive theory, the condition variable is the use of virtual laboratory media (T), the method variable is the application of the Flipp Classroom learning strategy (P), and the learning outcome variable is Student Mathematical Concept Understanding (CK). This type of research is pre-experimental research. The stages of conducting the study are described in Table 2.

Table 2. Teacher and Student Activities with The Flipp Classroom Learning Strategy

Flipped Classroom Flow	Teacher Activities	Student Activities
Before Class (Online activities before the meeting via WhatsApp group and YouTube)	1. Explain the learning objectives. 2. Provide apperception and exploration of learning materials through interactive media with the help of the lab. Virtual.	1. Listening to learning objectives. 2. Listen to interactive media in the lab. Virtual to find the concept of the material being studied.
In Class (Face-to-face activities in class)	3. Discuss the problems encountered in the before-class activities/which will be solved in learning. 4. Motivate students to be involved in problem-solving activities.	3. Presenting the problem / listening to the problem given. 4. Be actively involved in problem-solving activities.
	5. Divide the class into small groups. 6. Helping students to define and organize learning tasks related to the problem being solved.	5. Gather in groups. 6. Discuss the problems that will be studied in each group.
	7. Encourage students to collect appropriate information and experiment to get problem-solving explanations.	7. Students collect information, investigate, and ask questions to get answers to the problems they face.
	8. Assisting students in planning and preparing appropriate works and helping them share assignments with their friends.	8. Presenting the results of group discussions.
	9. Helping students reflect or evaluate their investigations and their processes.	9. Summarize the material and submit assignments as material for evaluating the learning process.
After Class (Online activities after meeting class via Whatsapp group)	10. Provide questions related to the material discussed as training material.	10. Do the practice questions given.

Virtual laboratory media, namely computer-based media that students can use to carry out simulations or experiments as they are done in actual laboratories. A virtual laboratory is a medium that provides a laboratory experience without a natural laboratory but in the form of a simulation on a computer. Contains various kinds of components such as hypertext, text,

sound, images, animation, video, and graphics [14]-[17]. Thus, the virtual laboratory is an interactive digital media that students can use to carry out practicum activities, which include experiments or simulations of learning materials, making it easier for students to achieve learning goals. An example of a virtual laboratory media display is presented in Fig. 3.

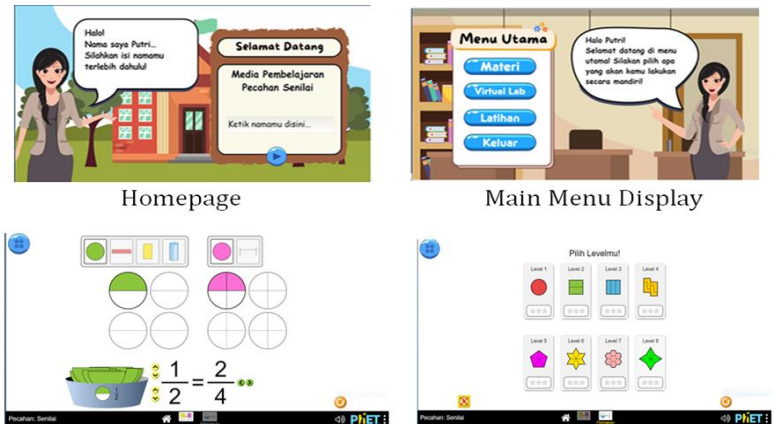


Fig. 3. Display of Virtual Laboratory Media in Fractional Material of Value

The Virtual Lab menu contains simulation and exploration of equivalent fraction material and is also equipped with a game menu with the topic of comparable fraction games. The impact test results of implementing the flipped classroom learning strategy assisted by virtual laboratory media (virtual lab) on the understanding of mathematical concepts for 8th-grade students are presented in Fig. 4.

Based on Fig. 4, it can be seen that 28% of students understood mathematical concepts with high criteria, 48% achieved medium standards, and 24% obtained low bars.

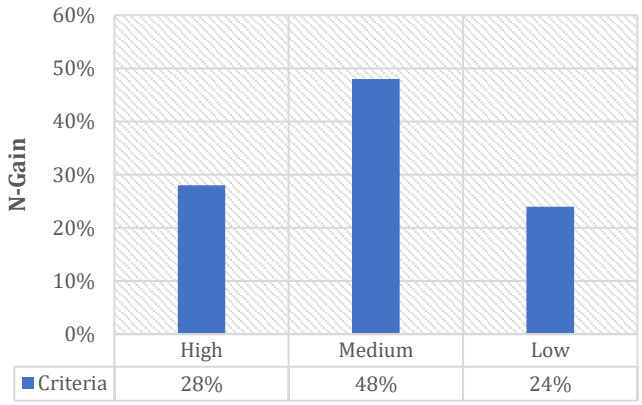


Fig. 4. N-gain Students' Mathematical Concept Understanding Scores

Discussion

TPACK (Technological Pedagogical and Content Knowledge) is the application of a learning system that prioritizes the application of specific technologies and applications in

learning. TPACK is a framework that identifies knowledge and how to convey it effectively and efficiently through technology integration. TPACK emphasizes the relationship between subject matter, technology and pedagogy. Technological knowledge is the basics of technology that can be used to support learning. Pedagogical knowledge that describes in-depth knowledge related to teaching and learning theory and practice, including lesson planning, learning implementation, and learning assessment, includes cognitive, affective, and psychomotor aspects. Content knowledge is knowledge of the subject matter to be studied. The curriculum contains this material, including knowledge of concepts, theories, ideas, frameworks, and methods supplemented by scientific methods and their application in everyday life. This is supported by research results and previously developed approaches [9],[18]-[21]. All aspects contained in the TPACK framework will influence the learning design.

Learning variables influencing learning design are learning conditions, methods, and outcomes. The learning condition variable is closely related to the choice of technology to facilitate learning. The choice of technology is very closely related to the subject matter to be taught. With the help of technology, subject matter that is difficult or that cannot be imagined by students can be assisted by making media, one of which is virtual laboratory media. This result aligns with a study by [15], which states that virtual laboratories can facilitate students to learn anytime, anywhere by exploring concepts through practicum without using a natural laboratory. The results of the meta-analysis revealed that through a virtual laboratory, student learning outcomes can be increased with a moderate effect size [16].

Learning conditions facilitated by technology, of course, will only be able to run effectively if applied in a relevant and appropriate way. The method used in the learning variable is included in the method variable. This method variable is an element of pedagogy in the TPACK framework. Thus, when applied to learning in the right ways, the technology that has been designed will be able to provide optimal results. The results of this study are supported by research results, which state that integrating technology into learning is critical in achieving optimal learning outcomes, so serious efforts are needed from schools to provide the necessary facilities [22]. Furthermore, research by Ref. [23] stated that teachers must have a good understanding and ability to integrate technology into learning. With this understanding and knowledge, learning will occur effectively according to its purpose.

Learning outcome variables are learning aspects, including knowledge, skills, attitudes, and all the impacts to be achieved, both instructional and accompanying. When associated with the TPACK framework, it is included in the content/ subject matter knowledge component. The results to be achieved in implementing learning are by the learning outcomes specified in the curriculum related to the material to be taught.

Thus, the learning variables with the TPACK framework can be one-to-one correspondence how the learning design will be developed is adjusted to the position of the theory, whether the idea is descriptive or prescriptive. Thus, it will produce a learning design study, for the descriptive approach will tend to lead to experimental studies (quasi-experimental), while prescriptive theory tends to lead to development studies.

Educational technology (ET) is a field of science that focuses on studies on how to facilitate people to learn more efficiently [6]. This digital era challenges implementing effective, efficient, and attractive learning. The role of ET in designing and developing knowledge is to determine the steps, including how to carry out a needs analysis, namely identifying the learning outcomes to be achieved, making an overall picture of the flow of presentation of the material from the teaching materials to be developed; collect appropriate materials/media; designing product drafts; to test product validity; in the final stage of conducting a feasibility test on the resulting product development. The results of this study are the results of research by Ref. [24], who concluded that instructional design is about developing, assessing, and evaluating learning.

The results of research on the impact of implementing interactive mathematics learning media integrated with virtual lab through the Flip Classroom learning strategy on understanding mathematics concepts for 8th-grade students, effectively increasing students' understanding of concepts, especially in flat-sided geometric material. However, 24% of students still need more knowledge of the concept. This shows that there are other factors besides the use of media that influence students' understanding of concepts. Therefore, learning with the Flipped Classroom learning strategy requires further research studies to obtain improvements in subsequent implementation.

Conclusion

The results of this study are that the elements in the TPACK framework and the learning variables can correspond one-to-one in designing learning according to the digital era, namely: the aspect of technology is closely related to the condition variable; pedagogic elements with method variables; and elements of knowledge about content with outcome variables. Based on a pre-experimental study conducted by integrating TPACK in learning according to descriptive learning theory, the gain score for students' understanding of mathematical concepts was obtained by implementing the flipped classroom learning strategy assisted by virtual laboratory media, namely: 28% of students achieved the high criteria; 48% achieved medium standards and 24% obtained low bars. It can be concluded that applying virtual laboratory learning media with the flipped classroom learning strategy effectively increases students' understanding of mathematical concepts. Based on the results of this study, there are still students whose knowledge of the concept is in the low category. Therefore, other

researchers should research using media in implementing the flipped classroom learning strategy to achieve optimal learning outcomes.

Conflict of Interest

The authors declare that there is no conflict of interest.

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