Digital Didactical Design: The Role of Learning Obstacles in Designing Combinatorics Digital Module for Vocational Students

https://doi.org/10.3991/ijim.v17i02.34293

Tri Nopriana[1,2](✉), Tatang Herman[1], Bambang Avip Priatna Martadiputra[1]
[1] Universitas Pendidikan Indonesia, Bandung, Indonesia
[2] Universitas Swadaya Gunung Jati, Cirebon, Indonesia
trinopriana@upi.edu

Abstract—Many changes occur in the world of education as a result of technological advancement, including the compilation of a module. Digital modules that students can easily access and that have been compiled based on an analysis of student learning obstacles are required. Therefore, this research aims to develop a digital module based on student learning obstacles and it employs the theory of Digital Didactical Design (DDD). DDD contains components of learning objectives, learning activities, process-based assessment, social relations, and integrated technology. This is an on-going study relying on ADDIE (Analyze, Design, Development, Implement, Evaluation) model and it reveals the results from Analyze, Design, and Development stages. In the analysis stage, several instruments, such as test, interviews, and documentation, were used to encounter some learning obstacles in solving the combination problems faced by the vocational high school students. The next stage is designing the digital module based on the students' learning obstacles using DDD components. And in the development stage, the validity and practicality of the module are being tested and the results are very valid and practical. Thus, this digital module was feasible and can be used in teaching combination for vocational high school students to minimize learning obstacles.

Keywords—combinatorics, digital didactical design, digital module, learning obstacle, vocational high school students

1 Introduction

Combinatorics requires special attention in mathematics, particularly for high school students, due to its abundance of contexts for problem-solving. Deep mathematical reasoning, critical thinking, logical reasoning, and keen insight are required to solve combinatorics problems [1]–[3]. Additionally, combinatorial applications are used in other fields of science such as computer science, communications, genetics and statistics [2]. Understanding the rules for counting in combinatorics is difficult for students, particularly when calculating the number of probabilities for an event using combinations, permutations, and multiplication rules [4]. There are two steps to teaching this material easily, namely understanding students' difficulties in solving combinatorics problems and identifying variables causing these difficulties [1].

Students' difficulties in combinatorics are studied by analyzing the obstacles they face in learning. There are three types of learning obstacles, namely ontogenic, didactic and epistemological obstacles [5]. Ontogenic obstacles are due to differences between the knowledge levels of students and teachers. Didactic obstacles are caused by the lack of appropriate methods or approaches used in teaching. Epistemological obstacles occur due to limited knowledge of a certain context [6]. To achieve success in learning permutation and combination materials, it is necessary to analyze students' obstacles when attempting to solve problems.

According to Suryadi (2019), one of the main issues causing learning obstacles in learning permutations and combinations is teaching material [6]. Several previous studies show that the design of teaching materials needs to be organized systematically to develop mathematical abilities, including mathematical communication, problem-solving activities, and combinatorial thinking skills [7]–[11]. Several previous studies suggest TDS as the theory to design the learning materials. TDS (Theory of Didactical Situations) is one theory to design a learning material, and it presents activities related to interactions between teachers, students, and mathematical knowledge. Brousseau (2002) describes didactic situations in several stages, including action, formulation, validation, and institutionalization [5], [12]. The training program provided in accordance with TDS had a positive impact on changing and developing students' attitudes toward mathematics education courses [13].

However, previous studies presented various mathematics learning materials with TDS in a paper-based form. It is necessary to design a didactic situation with technology integration. The incorporation of digital technologies into existing classroom practices allows digital technologies to potentially transform the way mathematics is taught and learned [14]. Digital Didactical Design (DDD) is one framework-related didactical situation (TDS) using technology integration.

DDD is a framework that views teaching, learning, and technology integration as a system of three components (teachers, students, and content) [15]. Therefore, the elements are teaching objectives, learning activities, process-based assessment, social relations, and technology integration [16], [17]. The digital term is a component of DDD that answers the need to design teaching materials using integration technology. With the incorporation of digital technologies into existing classroom practices, digital technologies have the potential to transform the way mathematics is taught and learned [18]. The link between mathematical practices and knowledge is strengthened in didactical situations involving effective uses of technology and vice versa [17], [18].

The use of digital products in mathematics lessons has been conducted in several studies, including game-based interactive Apps [19], [20], digital interactive math comics [21], virtual reality in online learning [22], digital books using articulate storyline software [23], and gamebooks [24]. However, these digital materials require a sufficient internet connection and high-tech devices. Therefore, this study selected the Flip PDF Corporation software application for designing digital modules on combination materials. Using Flip PDF Corporation, students can experience reading books in three dimensions with interesting features, such as videos, music, pictures, interactive quizzes, and active hyperlinks. Additionally, this digital module is easily accessible by students and only requires a minimal internet connection. Since lack of equipment or internet connection still the problem during digital times [25]. Therefore, this research aims to address the following questions:

a) What are the learning obstacles of vocational high school students in solving combination problems?
b) How can a digital module be designed based on an analysis of learning obstacles and DDD components?
c) Is the digital module that is arranged suitable for use?

The following section includes a review of the literature, research methods, findings, and a discussion of our study.

2 Literature review

2.1 Learning obstacles in combinatorics

Permutations and combinations are the difficult part of combinatorics [26]. Before finding clear instructions, permutation is the most challenging problem, even though the formula used is the most straightforward [27]. There has been a great deal of research into the teaching and learning of combinatorics in recent decades. Multiple studies have shown that less than half of students at various grade levels can correctly solve basic arithmetic problems, including permutations and combinations [3], [26]–[29]. Additionally, the results showed that students could structurally connect and conceptualize characteristic permutation problems more quickly [30]. Permutation and combination formulas were often misapplied, which indicates they may not understand when and why these formulas are used [31].

A number of studies have extensively discussed the students' learning obstacles in solving and understanding the concepts of permutation and combination problems. For instance, students are confused about which cases use the idea of permutations, which are combinations [3], [26], [32]. Students did the combination problem by using the permutation problem [33]. Students make several types of errors in solving permutation and combination problems. Students misinterpret the question, creation of solutions using wrong arithmetic operations, and wrong formulas used and disability to remember the meaning of values for parameters in combinatorics [32]. Students have difficulty making sense of permutations and combinations and have trouble with the meaning of these concepts [34].

Learning obstacles are experienced when learning mathematics from outside (external factors) [5]. In this study, learning obstacles are the main foundation in designing Digital Didactical Design (DDD). Researchers need to know the learning obstacles experienced by students before designing DDD. Brousseau defines three types of learning obstacles, namely ontogenic, didactic and epistemological obstacles [5]. Ontogenic obstacles are due to differences between the knowledge levels of students and teachers. Ontogenic research obstacles can be seen in student interviews regarding students' awareness of the benefits of combined material in everyday life and students' awareness when encountering unsolved problems. Didactic obstacles are caused by the lack of appropriate methods or approaches used in teaching. The didactic obstacles in this study can be seen in the examination of documentation of the teacher's teaching materials, student notes, and the results of interviews with students about classroom learning. Epistemological obstacles occur due to limited knowledge of a particular context. Epistemological obstacles can be identified by administering diagnostic tests, followed by interviews with students to identify obstacles and confirm students' thinking in completing the test. Therefore, when individuals are faced with a different context, the knowledge possessed becomes unusable [6].

2.2 Theory of didactical situation in designing learning material

The theory of didactic situations (TDS) is a theoretical model, developed by Guy Brrousseau, which provides the interaction between teacher, student and knowledge [5]. Several previous studies suggest TDS as the theory for designing learning materials. For instance, the design of circle material based on mathematical communication [8], [35] and learning activities in negative integers [36].

Brousseau described didactic situations in several stages, including (1) Action Situations, when students are faced with mathematical issues solved by mental actions. Without the teacher's intervention, the student must outline strategies, using reasoning and prior knowledge to formulate ways to solve the problem [37]. Action situations are successful when students can manage strategies and represent the given problems; (2) Students ultimately arrive at the formulation situation due to the mental action they perform. In the formulation situation, students can discuss the strategies used to solve the given problem in pairs or groups. The success of this situation is when the problem and construct plans are well understood to solve the given problem; (3) Validation Situation. After the formulation situation, a discussion called the validation situation is conducted. The teacher can influence and improve the strategies at this stage by providing explanations and theories; (4) Institutionalization Situation is the process of concluding learning outcomes and applying them to different contexts [5], [12]. The institutionalization situation is said to be successful in this study if students can complete the practice questions given.

To achieve justified knowledge, learning material must be designed using TDS. Because the didactic situation provides a path toward a more equitable mathematics curriculum that allows for greater access to powerful knowledge [38]. Recent studies used TDS as a complementarity theory to design didactical engineering to conceive and structure didactic situations aiming at its teaching [37], designing lesson plan using cabri geometry software [39]. However, the previous studies of TDS phases are shared in paper-based form. Based on earlier research, we elaborate on the TDS as a learning activity and present it with a digital form. Regarding the didactic approach that teachers should carry, it is critical to design mixed teaching techniques that will promote the teaching of mathematics while being harmoniously enhanced by the use of ICT in the form of computers or tablets [40].

2.3 Designing digital module using Digital Didactical Design (DDD)

Digital mathematics learning is considered effective and can increase satisfaction and quality of learning. Digital products help to meet the needs of today's native students by involving them in the teaching and learning process [21]. The advantages are the elements can be presented with digital teaching material that positively and practically impacts visual comprehension of the subject matter and interactive learning [41]. Furthermore, it improves the ability to practice the subject matter, especially for vocational students [42]–[44].

Digital Didactical Design, presented by Jahnke [16], was inspired by Hudson [45] and Lund & Hauge [46], which differentiated the concept of teaching and its activities. The didactic concept from Europe explains the content-student-teacher relationship. Jahnke complemented this concept to distinguish teaching and learning activities. Therefore, DDD provides a new perspective on didactic and design activities [16]. One of the central components is the cultivation of social relations. In this digital era, technology affects many layers of education, from classroom reactions, content in learning, activities and agendas outside the school to local and national decision-making [47]. DDD uses the term digital because, in an Internet-driven world, teaching practices are typically technology-based. However, the degree to which they support various forms of learning varies depending on the quantity and quality of technology integration [16], [48]. Technology integration in teaching affects the existing didactic design.

The main components are Teaching objectives, Process-based Assessment, and Learning activities delivered through digital media in a social context. Innovation and technology use lead to new learning situations at different levels. Technology-based media produces multiple layers in education, influencing how humans interact with knowledge content in the classroom and producing various effects on the didactic process. The following are five design elements and their ideal characteristics for deep and meaningful learning in DDD [16], [47], [49]: Firstly, learning objectives and expected outcomes are clear and visible to students. The learning objectives in this study are based on essential competencies and indicators of competency achievement. Secondly, learning activities help students to achieve the learning objective. This study's learning activities are based on the theory of didactical situations [5]. Thirdly, the process-based assessment allows students to receive guided reflection for performance or skill development. This study presents a process-based assessment by raising problems that can lead to group discussion activities and live worksheets. Fourthly, social relations, for example, teachers are experts and processing mentors and learning companions. Discussion activities between students or between students and teachers include the social relations component. Fifthly, technology integration is required in DDD since students document learning and create products.

The earlier research showed technology integration in didactical design implemented using iPad [17], [47], [50], [51], digital and tangible artefacts [52]. However, this integration technology requires special devices that must be owned by students and teachers. This study incorporates technology that teachers and students can easily access from anywhere at any time using only their mobile phones. The technology integration in this study is presented as a digital module via the Flip PDF Corporation application, which is accessible via the web. The digital module also includes DDD components such as learning objectives, learning activities, process-based assessment, and social relations. Learning videos, material explanation videos, interactive quizzes, live worksheets, and links to practice questions and assignment collections are among the digital modules that have been compiled.

3 Methodology

The Research and Development with ADDIE (Analysis, Design, Development, Implementation, Evaluation)[53] model was used to analyze student learning obstacles in solving combinations, develop DDD in a digital module, and test the validity and practicality of Digital Didactical Design by expert and student.

3.1 Design research

This research consists of Analysis, Design, and Development stages. The first stage was the analysis stage, conducted by analyzing the learning obstacle of students in solving the problem of the rules of enumeration. The second is the design stage, prepared using the theory of didactical situations [5]. First, the module is compiled in pdf format using the graphic design application www.canva.com. Some didactic situations were given in writing tasks, learning activities, and videos collected with the videoScribe application. In addition to being compiled, the digital module is also structured based on 5 DDD components (learning objectives, learning activities, process-based assessment, social relations, and technology integration). After the module's content has been created, the entire DDD in digital teaching materials is presented using the Flip PDF Corporation application.

The third stage is the Development stage by conducting a digital module feasibility test. Furthermore, the feasibility test of the digital module is seen from the validity and practicality tests. Vocational high school mathematics teachers and Education Lecturers carried out the validity test. At the same time, teachers and students conducted the practicality test.

3.2 Participant

A test was administered to 26 grade 12 students from a vocational high school who had studied combination material to determine students' learning obstacles in solving combinatorics problems. As expert validators, the help of four mathematics teachers with master's degrees was enlisted from a state vocational high school in Cirebon City and two mathematics education lecturers with doctorates. Additionally, five students were included in grade 12 of a vocational high school in Cirebon City to test the practicality of the compiled digital module. All ethical procedures were observed for the entire duration of the study. A letter of permission was requested from the Director of a Vocational High School in Cirebon City to observe student learning obstacles, conduct discussions with teachers, implement digital modules and gather experiences about their use. The participants believe that all data collected is confidential and used only for research purposes. In this study, the names of the validators and research respondents were disguised.

3.3 Research instrument

In collecting data and instruments, several ways were used to design a module digital, as follows:

1. At the analysis stage, the instruments used include essay tests, learning documentation in the form of teaching materials used by teachers and student notes, and interview guidelines. An essay test was conducted to identify students' learning obstacles in solving enumeration problems. The essay test consists of five questions that are thought to be valid and reliable. Documentation studies were conducted to observe the teaching materials used by the teacher and the notes held by the students. The studies analyzed learning obstacles related to the design of teaching materials. Interview guidelines were prepared to determine the types of student learning obstacles in solving the enumeration problems described in Table 1.

Table 1. Student learning obstacle analysis interview guide

No	Component	Questions
1	Ontogonic Obstacle	Do you know that studying permutations and combinations has many practical applications?
		What do you do when you find a difficult problem in an assignment related to the rules of fractionation?
2	Didactical Obstacle	Do you understand the material on enumeration rules?
		How are learning activities based on enumeration rules material implemented?
		What learning resources does the teacher use when teaching the material on enumeration rules?
		Which part of the material for counting rules (permutations and combinations) is the most difficult to understand?
3	Epistemological Obstacle	What challenges did you face while working on the given questions?
		Have the questions that you worked on been introduced in class?
		Which question is the most difficult? Why do you find it difficult?

2. At the development stage, the instruments used to test the feasibility of the digital module were given in the form of validation and practicality questionnaires. Meanwhile, the module validation questionnaire consists of learning media and pedagogy aspects. The questionnaire assessment uses a 4-1 Likert scale to determine its quality [54]. Table 2 describes the indicator of media and material expert judgment.

Table 2. Indicator of media and pedagogy expert judgement [23]

No	Aspect	Indicator
1	Learning Media	Digital Module Component
		Typography of Contents
		Textual and Visual Media Elements
		Interactivity
2	Pedagogy	Material Content
		Didactic situation in module
		User Interest

The digital module practicality test is based on the following indicators (1) The clarity of each component in the Digital Module, (2) The accuracy of media and features in the digital module, (3) The suitability of the instructions, materials and examples and practice questions presented in the digital module, (4) Clarity of instructions for use, display buttons, and links in digital modules, (5) Matching letters and colours in digital modules, (6) Ease of using digital modules.

3.4 Data analysis

The qualitative data analyzed students' learning obstacles through tests, documentation studies, and interview guidelines. The following stages of qualitative data analysis were completed (1) processing and preparing the data for the analysis stage, (2) recapitulating test results, writing interview transcripts, (3) identifying learning obstacle based on test results and interviews. (4) designing a digital module related to student learning obstacles in solving combination material.

Quantitative data is obtained through validation sheets and practical judgment. The analysis is conducted using descriptive statistics. Table 3 contains the average scores given by learning media validators, pedagogy and practical validators, scores from the Likert scale, and validity/practical categories of the digital module.

Table 3. Likert scale for assessment[55]

Average score (X) to the given category	Related Score	Category (Alternative Answers)
$X > 4.21$	5	Very Valid/Very Good
$3.40 \leq X \leq 4.21$	4	Valid/Good
$2.60 \leq X \leq 3.40$	3	Acceptable
$1.79 \leq X \leq 2.60$	2	Less valid/Poor
$X \leq 1.79$	1	Invalid/Very Poor

4 Results and discussion

4.1 Analyze student learning obstacles

The first stage in designing a digital module on combination materials is to analyze learning obstacles. They are the result of the analysis, including the textbooks the teacher used and the notes the students held to discover the didactical obstacle. Furthermore, interviews were conducted to determine the ontogenic obstacle to students' learning readiness, especially on the material of the counting rules. Epistemological obstacle analysis analyses the student's answers sheet and confirms them through interviews. The detailed analysis is described in the summary of the student's learning obstacles in solving combination problems in Table 4.

Table 4. Summary of student learning obstacle analysis

Learning Obstacle	Summary of Learning Obstacle
Ontogenic Obstacle	Students are unaware of the combination concept and its application in everyday life. They would directly ask a friend or copy their work when presented with difficult tasks.
Didactical Obstacle	• Students admitted that they did not understand the material on enumeration rules. This is because learning is not carried out optimally, and no feedback is provided when students have completed the assigned task. Furthermore, they only learn from learning resources provided/sent by the teacher. Students will be happier when the teacher explains directly, either online or offline, after providing material for study. • Students explain that they learn in Google Classroom, and the teacher provides material in the form of PPT slides and Word documents. The students were asked to answer practice questions on paper and upload assignments to Google Classroom. • Based on the teaching materials and student notebooks, the teacher immediately introduced the examples and did not explain further the conditions for using the concepts of permutations and combinations. The most challenging part of the material on counting rules is determining the formula when the problem is combined between permutations and combinations.
Epistemological Obstacle	• Students struggle to solve problems that differ from the examples provided by the teacher. • Students cannot differentiate the conditions of permutations or combinations given in the problem. • Students can calculate each possibility but struggle to complete the final part of the problem involving multiplication and addition rules when there are two conditions. • Students have not been able to determine all possible outcomes. • Students are not permitted to re-explain the conditions stated in the questions.

After completing the learning obstacle analysis, a Hypothetical Didactical Design was created, which is a didactic situation design based on the newly discovered learning obstacles. According to DDD theory, this didactic situation is part of learning activities also presented using technology integration. Table 5 provides examples of learning obstacle analysis and didactic design outcomes in digital module presentations and didactic anticipation.

Table 5. Example of hypothetical didactical design

Learning Obstacle	Digital Didactic Situation	Response Prediction	Pedagogical Didactical Anticipation
• Students do not know and realize the benefits of using combinations in everyday life. • The combination material is explained by introducing the formula and followed by examples.	Students are given a video containing motivation regarding applying the concept of counting rules, such as permutations and combinations, in everyday life. They are shown a video about the different combinations and their application in everyday life. These consist of several ways to determine the combination of clothes and pants that can be worn.	Expected response: Students know and realize the benefits of using combinations in everyday life • They learn engaging illustrations and are not immediately introduced to formulas. • The provided answers can be checked through a pop-up image from a digital book	• The teacher asks students to explain what they understand from the video. • The teacher guides students by asking what is known about the problems. • alternative ways to solve the problem are then provided.

4.2 Design Digital Didactical Design (DDD)

The following research stage was to create a digital module design using DDD components and the theory of the didactical situation. DDD has five components, namely learning objectives, activities that include the theory of didactical situation, process-based assessment, social relations, and technology integration. The first component was learning objectives and expected learning. This section is presented in a cover, instructions for using the module, and learning objective in digital modules as described in Figure 1, Figure 2 and Figure 3.

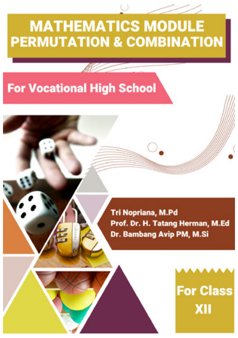

Fig. 1. Cover digital module

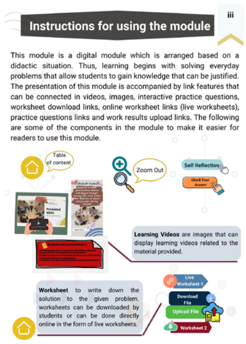

Fig. 2. Digital module user manual

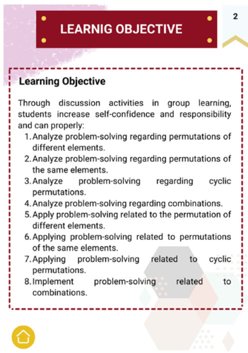

Fig. 3. Learning objective

The material's cover, the author's identity, and the class groups of the module users comprise the digital module. The user manual explains the menu options students can access and the components of learning activities. Furthermore, learning objectives are developed based on basic competency descriptions and indicators of competency achievement.

The second component of DDD is learning activities. Learning activities in this digital module are organized around the theory of didactical situation, which consists of conducting experiments, generalizing, concluding, and practicing, as seen in Figures 4, 5, 6, and 7.

Students learning activities in conducting color mixing experiments are depicted in Figure 4. This experimental activity allows students to engage in conversations with their peers. Furthermore, students are expected to conclude that the rules are ignored when mixing colors. The result will be the same regardless of the order in which the colors are drawn when there are three to be mixed.

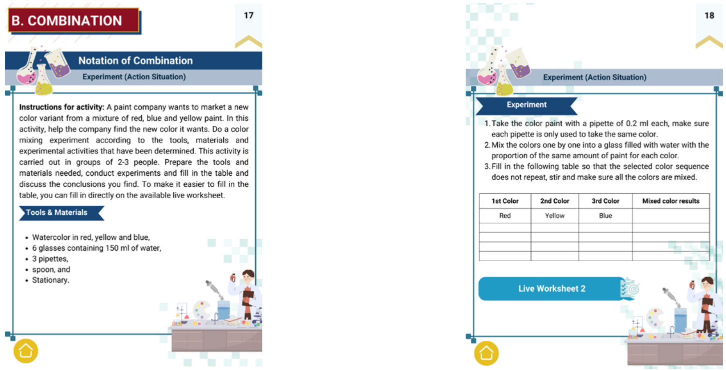

Fig. 4. Learning Activities in conduct experiment (action situation)

Students are instructed to find a combination formula by calculating the permutations of mixing two colors from the three available (Figure 5). The results of mixing the two colors remained the same even when the order mixed first varied.

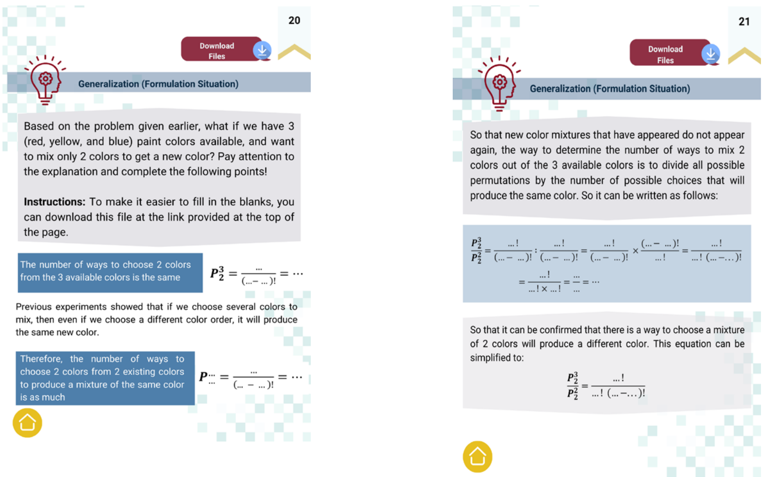

Fig. 5. Learning activity in generalize (formulation situation)

In conclusion, the combination formula is obtained from the permutation formula divided by the permutations of the same color mixture (Figure 6). The teacher helps students find general forms and simplify combination formulas at this stage. The teacher confirms based on the findings obtained. After determining the general formula for the combination, the teacher assigned the students to practice questions in essays (Figure 7). Students are given practice questions to ensure they have mastered the given combination material and can apply the combination concept in different contexts.

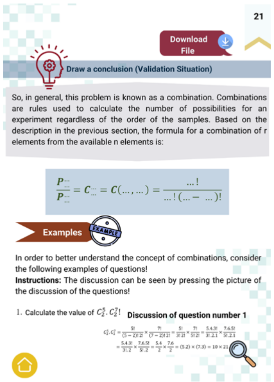

Fig. 6. Learning activity in draw conclusions (validation situations)

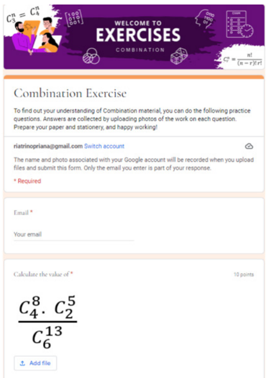

Fig. 7. Learning activity in doing exercise (institutionalization situations)

The third component of DDD is process-based assessment. The teacher assesses during and at the end of the lesson. The teacher observes students' problems with the hypothetical didactic design while using digital modules to assess their progress. In addition to evaluating abilities to master the material, teachers also assess skills in using digital modules. Process-based assessment is seen and presented in essay form in the evaluation section. Therefore, the teacher can see the students' difficulties when an error occurs, and the exercise section is displayed in Figure 7.

The fourth component of DDD is Social Relations. Social relations in the digital module that is collected is that the teacher allows interaction between students and students or students and teachers during learning. The social relations between people in discussions to resolve a didactic situation are given in the digital module, as shown in Figure 4. Experimental activities carried out in groups allow for social interaction between teachers with students and teachers with modules. The teacher's role in the discussion is as a facilitator who confirms the truth of the knowledge that students have achieved or helps in the form of stimulus questions to students. The assistance provided by the teacher is known as pedagogical didactical anticipation, arranged in a hypothetical didactical design.

The fifth component in DDD is technology integration. Technology integration has been reflected since the beginning of digital modules. Before beginning to study the combination material, an interactive quiz was created to assess students' comprehension of the previous material (Figure 8). Furthermore, a video that contains a review of the material was created for students to recall it by watching the video (Figure 9) and a discussion of sample questions compiled using Video Scribe application. The presentation of technology integration in digital modules is described in the following pictures.

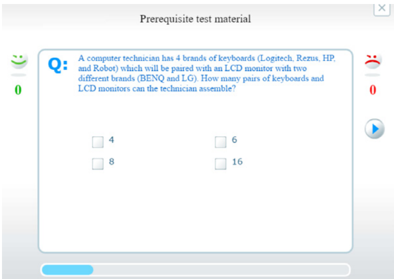

Fig. 8. Interactive quiz

Fig. 9. Review material video

4.3 Development of Digital Didactical Design (DDD)

After the digital module design based on DDD theory has been compiled, three stages of validity are carried out to determine its feasibility. These include the validity of the learning media and pedagogy and practical judgement. The validator of these digital module consists of a doctor of mathematics education as a lecturer and a master of mathematics education as a mathematics teacher. The results of the six validators on the combined digital module are as follows.

Table 6 shows the average media expert validation score of the six validators on the overall combination of the digital module, which is 4.82, including in the very valid categories. Therefore, the media aspect was properly designed, including the digital module component, typography of contents, textual and visual media elements, and interactivity. This aspect is essential to design because it relates to student motivation properly. Technology content in a well-organized digital module can raise students' motivation and interest in mathematics, especially in learning combination material. Designing a digital module motivated them to learn mathematics [56].

Table 6. The validation of expert judgement

Validator	Media Expert		Pedagogy Expert	
	Average Score	***Categories***	***Average Score***	***Categories***
Validator 1	4.94	Very Valid	4.85	Very Valid
Validator 2	4.94	Very Valid	4.92	Very Valid
Validator 3	4.94	Very Valid	4.92	Very Valid
Validator 4	4.82	Very Valid	4.92	Very Valid
Validator 5	4.41	Very Valid	4.15	Valid
Validator 6	4.88	Very Valid	4.85	Very Valid
Average	4.82	Very Valid	4.77	Very Valid

The average score of pedagogy experts shows that the digital module compiled is very valid. All the pedagogy aspects, including material content, the didactic situation in the module, and user interest, are deemed appropriate by the validator. Subsequently, a practical test was conducted on 2 mathematics teachers and 5 vocational high school students who had studied the combination material. The results of the practicality test can be seen in Table 7.

Table 7. Practicality judgement

Responded	Average Score	Categories
Teacher 1	4.86	Very Good
Teacher 2	4.95	Very Good
Student 1	4.82	Very Good
Student 2	4.36	Very Good
Student 3	4.95	Very Good
Student 4	4.77	Very Good
Student 5	4.68	Very Good
Average	**4.77**	**Very Good**

Practicality testing shows an average value of 4.77 in the very good category. All respondents agreed that the digital module, created using the DDD component and learning obstacles, was extremely practical. Based on the validity and practicality tests, which have very valid and very good categories, the digital modules compiled are suitable for teaching combination materials for vocational high school students.

4.4 Discussion

The first research stage was to analyze students' learning obstacles in solving combination problems. The analysis and classification were based on tests, interviews, and documentation studies using teacher teaching materials and student notes. The results of the learning obstacle analysis are in line with the results of previous studies. It was stated that difficulties arise due to several errors, such as confusion about the use of permutations [3], [8], [14], students solving the combination problem by using the permutation problem [15], misinterpretation of the question, creation of solutions using incorrect arithmetic operations, an incorrect formula used, and inability to remember the meaning of values for parameters in combinatorics formula [14], and problems with the meaning of these concepts [34]. In general, students still experience learning obstacles in solving combination problems, hence the digital module design can be an effort to minimize the learning obstacle.

The next step is to design a digital module compiled using the PDF Flip Corporation application. This application consists of features such as interactive quizzes, videos, hyperlinks related to living worksheets, practice question links, and assignment collection. Furthermore, the tools for visualizing mathematical concepts on the web and in the form of apps that can teach mathematics are available in various search engines [57]. Before using digital modules, the instructions need to be studied by students.

Interactive quizzes were given at the beginning of learning to determine students' understanding of the previous material. The Interactive Questions were raised to obtain answers and get a right or wrong response. The feedback was more effective than other activities in engaging students to improve their results [58]. Additionally, interactive elements such as quizzes and videos help students improve performance and media richness theory [59]. A video review of the material is given when students do not understand the material in the previous discussion on additional rules, multiplication rules, filling slots, and permutations. Students who score less than 60% on the preliminary knowledge test can review the material presented in the video. Electronic modules allow the development of teaching materials by attaching videos presented concisely and efficiently for students to understand [34].

Some of these features support students in assessing the practicality of the digital module in the very good category. These findings are consistent with previous research, obtaining that using interactive mobile mathematics applications with visuals supports mathematics learning [21]. The use of digital modules in learning provides many advantages, including free content for use [34].

The feasibility of the digital module is assessed by the value of the validity of learning media and pedagogy by six media and material experts and the practicality judgment by five vocational students. The module should be appropriately arranged for easy understanding [55]. A feasible digital module can interact between teachers and students in the learning process [23]. Learning media validation sheets consist of digital module components, the typography of contents, textual and visual media elements, and interactivity. The learning media is categorized as "Very Valid" by obtaining an average score of 4.82 out of 5. Feasibility judgments were also found in compiling android-based e-textbooks [59]. Meanwhile, the use of technology in mathematics learning combined with appropriate software makes a significant contribution to student engagement with mathematics by embedding the subject in authentic contexts [14], [18], [40], [60]. Adaptive learning with new technology can help learners to get closer to their desires, needs, and methods [61].

5 Conclusion

The use of technology, specifically digital modules, is required to assist students in learning mathematics. This research aims to develop a digital module based on vocational students' learning obstacles and produce a feasible module for learning combinations. The learning media and pedagogy experts' judgment found that the digital module obtained in the "very valid" category. These results indicate that the digital module developed has good conditions, typography of contents, textual and visual elements, interactivity, material content, didactical situation, and user interest. The practicality test result indicates that the digital module was in the "very good" category with mean 4. 77 of 5.

The modules offered in digital form make it easier to input several learning resources, such as videos, illustrated images, and well-documented practice questions. Additionally, this research contributes to reducing the learning obstacle of vocational high school students in solving combination problems. Further analysis can be conducted by implementing this digital module for students with similar learning obstacles.

In the future, the study's limitations should be considerably addressed. The digital module was only given to small classes of five students during implementation. Therefore, additional research can be conducted on many students, and learning activities using digital modules can be observed. The study was limited to secondary vocational education and applied to students with similar learning obstacles.

6 Acknowledgements

We thank the anonymous reviewers for their great feedback in improving our work. We also appreciate all of the student and teacher participants for contributing to our research. Gratitude is also sent to Lembaga Pengelola Dana Pendidikan (LPDP) for funding our study.

7 References

[1] E. Lockwood, "A model of students' combinatorial thinking," *J. Math. Behav.*, vol. 32, no. 2, pp. 251–265, 2013, https://doi.org/10.1016/j.jmathb.2013.02.008

[2] E. Lockwood, "The Strategy of Solving Smaller, Similar Problems in the Context of Combinatorial Enumeration," *Int. J. Res. Undergrad. Math. Educ.*, vol. 1, no. 3, pp. 339–362, 2015, https://doi.org/10.1007/s40753-015-0016-8

[3] E. Lockwood and C. A. Swinyard, "An Introductory Set of Activities Designed to Facilitate Successful Combinatorial Enumeration for Undergraduate Students," *Primus*, vol. 26, no. 10, pp. 889–904, 2016, https://doi.org/10.1080/10511970.2016.1194934

[4] J. Wroughton and J. Nolan, "Pinochle poker: An activity for counting and probability," *J. Stat. Educ.*, vol. 20, no. 2, 2012, https://doi.org/10.1080/10691898.2012.11889642

[5] G. Brousseau, *Theory of Didactical Situations in Mathematics*. 2002.

[6] D. Suryadi, *Landasan Filosofis Penelitian Desain Didaktis (DDR)*. Bandung : Pengembangan DDR Indonesia: Gapura Press, 2019.

[7] T. Nopriana, C. Dwi Rosita, and I. Rosita, "Desain Didaktis Konsep Penjumlahan Dan Pengurangan Bilangan Bulat Pada Pembelajaran Matematika SMP," *Pros. SNMPM II*, pp. 310–319, 2018, [Online]. Available: http://www.fkip-unswagati.ac.id/ejournal/index.php/snmpm/article/view/402%0Ahttp://www.fkip-unswagati.ac.id/ejournal/index.php/snmpm/article/download/402/340

[8] C. D. Rosita, T. Nopriana, and I. Silvia, "Design of Learning Materials on Circle Based on Mathematical Communication," *Infin. J.*, vol. 8, no. 1, p. 87, 2019, https://doi.org/10.22460/infinity.v8i1.p87-98

[9] T. Nopriana, S. Firmasari, and T. Tonah, "Desain Bahan Ajar Berbasis Aktivitas Pemecahan Masalah Pada Pokok Bahasan Barisan Dan Deret," *Euclid*, vol. 2, no. 2, pp. 251–263, 2015, https://doi.org/10.33603/e.v2i2.361

[10] D. Suryadi, K. Yulianti, and E. Junaeti, "Model Antisipasi Dan Situasi Didaktis Dalam Pembelajaran Matematika Kombinatorik Berbasis Pendekatan Tidak Langsung," *Procedia - Soc. Behav. Sci.*, vol. 12, no. 1, pp. 665–670, 2010.

[11] A. Ammamiarihta, E. Syahputra, and E. Surya, "Development of Learning Devices Oriented Problem Based Learning to Increase Student's Combinatorial Thinking in Mathematical

Problem Solving Ability," vol. 104, no. Aisteel, pp. 334–339, 2017, https://doi.org/10.2991/aisteel-17.2017.71
[12] G. Brousseau and V. Warfield, "Didactic Situations in Mathematics Education," *Encycl. Math. Educ.*, vol. 66, no. 2007, pp. 163–170, 2014, https://doi.org/10.1007/978-94-007-4978-8_47
[13] M. E. E. Gök, "Examining the Attitude Change of Pre-Service Elementary School Teachers towards a Course of Mathematics Education within the Framework of Theory of Didactical Situations.," *Int. Online J. Educ. Teach.*, vol. 6, no. 4, pp. 879–904, 2019, [Online]. Available: http://iojet.org/index.php/IOJET/article/view/665
[14] S. Papadakis, M. Kalogiannakis, and N. Zaranis, "The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece," *Educ. Inf. Technol.*, vol. 23, no. 5, pp. 1849–1871, 2018, https://doi.org/10.1007/s10639-018-9693-7
[15] G. Sensevy, "About the joint action theory in didactics," *Zeitschrift fur Erziehungswiss.*, vol. 15, no. 3, pp. 503–516, 2012, https://doi.org/10.1007/s11618-012-0305-9
[16] I. Jahnke, L. Norqvist, and A. Olsson, "Digital didactical designs of learning expeditions," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 8719 LNCS, no. January, pp. 165–178, 2014, https://doi.org/10.1007/978-3-319-11200-8_13
[17] I. Jahnke, P. Bergström, E. Mårell-Olsson, L. Häll, and S. Kumar, "Digital Didactical Designs as research framework: iPad integration in Nordic schools," *Comput. Educ.*, vol. 113, pp. 1–15, 2017, https://doi.org/10.1016/j.compedu.2017.05.006
[18] S. Papadakis, M. Kalogiannakis, and N. Zaranis, "Teaching mathematics with mobile devices and the Realistic Mathematical Education (RME) approach in kindergarten," *Adv. Mob. Learn. Educ. Res.*, vol. 1, no. 1, pp. 5–18, 2021, https://doi.org/10.25082/AMLER.2021.01.002
[19] R. C. Chang and C. Y. Yang, "Developing a mobile app for game-based learning in middle school mathematics course," *2016 Int. Conf. Appl. Syst. Innov. IEEE ICASI 2016*, pp. 5–6, 2016, https://doi.org/10.1109/ICASI.2016.7539807
[20] T. Kärki, J. McMullen, and E. Lehtinen, "Improving rational number knowledge using the NanoRoboMath digital game," *Educ. Stud. Math.*, vol. 110, no. 1, pp. 101–123, 2022, https://doi.org/10.1007/s10649-021-10120-6
[21] L. A. Mamolo, "Students' evaluation and learning experience on the utilization of Digital Interactive Math Comics (DIMaC) mobile app," *Adv. Mob. Learn. Educ. Res.*, vol. 2, no. 2, pp. 375–388, 2022, https://doi.org/10.25082/AMLER.2022.02.006
[22] C. Kustandi, D. N. Fadhillah, R. Situmorang, D. S. Prawiradilaga, and S. Hartati, "VR use in online learning for higher education in Indonesia," *Int. J. Interact. Mob. Technol.*, vol. 14, no. 1, pp. 31–47, 2020, https://doi.org/10.3991/ijim.v14i01.11337
[23] B. Budiamai, K. Komarudin, N. Nuruddin, and C. Kustandi, "Learning Design on Social Studies Through Digital Book in Senior High School," *Int. J. Interact. Mob. Technol.*, vol. 15, no. 9, pp. 154–166, 2021, https://doi.org/10.3991/ijim.v15i09.18435
[24] J. Bidarra, M. Figueiredo, and C. Natálio, "Interactive design and gamification of ebooks for mobile and contextual learning," *Int. J. Interact. Mob. Technol.*, vol. 9, no. 3, pp. 24–32, 2015, https://doi.org/10.3991/ijim.v9i3.4421
[25] K. Lavidas, Z. Apostolou, and S. Papadakis, "Challenges and Opportunities of Mathematics in Digital Times: Preschool Teachers' Views," *Educ. Sci.*, vol. 12, no. 7, 2022, https://doi.org/10.3390/educsci12070459

[26] E. Lockwood, "Student connections among counting problems: An exploration using actor-oriented transfer," *Educ. Stud. Math.*, vol. 78, no. 3, pp. 307–322, 2011, https://doi.org/10.1007/s10649-011-9320-7
[27] J. Melusova and K. Vidermanova, "Upper-secondary Students' Strategies for Solving Combinatorial Problems," *Procedia - Soc. Behav. Sci.*, vol. 197, no. February, pp. 1703–1709, 2015, https://doi.org/10.1016/j.sbspro.2015.07.223
[28] M. M. Eizenberg, "Students ' Verification Strategies for Combinatorial Problems Students ' Verification Strategies for Combinatorial Problems," *Math. Think. Learn.*, vol. 6, no. 1, pp. 15–36, 2009, https://doi.org/10.1207/s15327833mtl0601_2
[29] J. D. Godino, C. Batanero, and R. Roa, "An onto-semiotic analysis of combinatorial problems and the solving processes by university students," *Educ. Stud. Math.*, vol. 60, no. 1, pp. 3–36, 2005, https://doi.org/10.1007/s10649-005-5893-3
[30] N. H. Wasserman, "Exploring Teachers' Categorizations For And Conceptions Of Combinatorial Problems," *Proc. 40th Annu. Meet. Res. Counc. Math. Learn.*, no. March, pp. 26–30, 2013.
[31] C. Batanero, V. Navarro-Pelayo, and J. D. Godino, "Effect of the impeicit combinatoriae modee on combinatoriae reasoning in secondary school pupies," *Educ. Stud. Math.*, vol. 32, no. 2, pp. 181–199, 1997, https://doi.org/10.1023/A:1002954428327
[32] R. Usry, R. Rosli, and S. Mistima Maat, "An Error Analysis of Matriculation Students' Permutations and Combinations," *Indian J. Sci. Technol.*, vol. 9, no. 4, 2016, https://doi.org/10.17485/ijst/2016/v9i4/81793
[33] S. Sukoriyanto, T. Nusantara, S. Subanji, and T. D. Chandra, "Students' Errors in Solving the Permutation and Combination Problems Based on Problem Solving Steps of Polya," *Int. Educ. Stud.*, vol. 9, no. 2, p. 11, 2016, https://doi.org/10.5539/ies.v9n2p11
[34] Kimani, M. Patrick, T. Renamarie, Gibbs, and M. Sarah, "Restoring Order to Permutation and Combination," *Math. Teach. Middle Sch.*, vol. 5, no. 1, pp. 430–438, 2013, https://doi.org/10.1145/2568195.2568204
[35] T. Nopriana, C. D. Rosita, D. Halbi, and U. S. Gunung, "K r e a n o," vol. 13, no. 1, pp. 100–112, 2022. https://doi.org/10.15294/kreano.v13i1.32620
[36] N. F. Fuadiah, D. Suryadi, and Turmudi, "Teaching and learning activities in classroom and their impact on student misunderstanding: A case study on negative integers," *Int. J. Instr.*, vol. 12, no. 1, pp. 407–424, 2019, https://doi.org/10.29333/iji.2019.12127a
[37] F. R. V. ALVES, A. M. da SILVA CAMILO, F. C. F. FONTENELE, and P. M. M. C. CATARINO, "Didactical Engineering in the Conception of a Teaching Situation Originated from Brazil´s SPAECE Assessment with the Support of the GEOGEBRA Software," *Acta Didact. Napocensia*, vol. 14, no. 2, pp. 84–98, 2021, https://doi.org/10.24193/adn.14.2.7
[38] P. Wright, A. Fejzo, and T. Carvalho, "Progressive pedagogies made visible: Implications for equitable mathematics teaching," *Curric. J.*, vol. 33, no. 1, pp. 25–41, 2022, https://doi.org/10.1002/curj.122
[39] E. Selman and M. S. Tapan-Broutin, "Teaching Symmetry in the Light of Didactic Situations," *J. Educ. Train. Stud.*, vol. 6, no. 11a, p. 139, 2018, https://doi.org/10.11114/jets.v6i11a.3811
[40] S. Papadakis, M. Kalogiannakis, and N. Zaranis, "Comparing Tablets and PCs in teaching Mathematics: An attempt to improve Mathematics Competence in Early Childhood Education," *Presch. Prim. Educ.*, vol. 4, no. 2, p. 241, 2016, https://doi.org/10.12681/ppej.8779
[41] M. J. Koehler, P. Mishra, and W. Cain, "What is Technological Pedagogical Content Knowledge (TPACK)?," *J. Educ.*, vol. 193, no. 3, pp. 13–19, 2013, https://doi.org/10.1177/002205741319300303

[42] D. P. Zwart, J. E. H. Van Luit, O. Noroozi, and S. L. Goei, "The effects of digital learning material on students' mathematics learning in vocational education," *Cogent Educ.*, vol. 4, no. 1, 2017, https://doi.org/10.1080/2331186X.2017.1313581
[43] R. Rabiman, M. Nurtanto, and N. Kholifah, "Design and development E-learning system by learning management system (Lms) in vocational education," *Int. J. Sci. Technol. Res.*, vol. 9, no. 1, pp. 1059–1063, 2020.
[44] J. Widodo, S. Sutaryadi, C. H. A. Dirgatama, and A. W. Wirawan, "Feasibility test application of information systems in the media as a learning in vocational school," *J. Educ. Learn.*, vol. 14, no. 1, pp. 28–33, 2020, https://doi.org/10.11591/edulearn.v14i1.14674
[45] B. Hudson, "A didactical design perspective on teacher presence in an international online learning community," *J. Res. Teach. Educ.*, vol. 15, no. 3, pp. 1–16, 2008, [Online]. Available: http://www.diva-portal.org/smash/record.jsf?pid=diva2:158554
[46] A. Lund and T. Eiliv Hauge, "Designs for Teaching and Learning in Technology-Rich Learning Environments," *Nord. J. Digit. Lit.*, vol. 6, no. 4, pp. 258–271, 2011, https://doi.org/10.18261/ISSN1891-943X-2011-04-05
[47] I. Jahnke and S. Kumar, "Digital Didactical Designs: Teachers' Integration of iPads for Learning-Centered Processes," *J. Digit. Learn. Teach. Educ.*, vol. 30, no. 3, pp. 81–88, 2014, https://doi.org/10.1007/978-3-319-11200-8_13
[48] I. Jahnke, L. Norqvist, and A. Olsson, "Digital didactical designs of learning expeditions," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 8719 LNCS, no. Iml, pp. 165–178, 2014, https://doi.org/10.1007/978-3-319-11200-8_13
[49] I. Jahnke, N. V. Svendsen, S. K. Johansen, and P. O. Zander, "The dream about the magic silver bullet - The complexity of designing for tablet-mediated learning," *Proc. Int. ACM Siggr. Conf. Support. Gr. Work*, pp. 100–110, 2014, https://doi.org/10.1145/2660398.2660404
[50] I. Jahnke, L. Norqvist, and A. Olsson, "Designing for iPad-classrooms," *Proc. Eur. Conf. Comput. Coop. Work*, pp. 21–25, 2013.
[51] L. Kopciewicz and H. Bougsiaa, "Understanding emergent teaching and learning practices: iPad integration in Polish school," *Educ. Inf. Technol.*, vol. 26, no. 3, pp. 2897–2918, 2021, https://doi.org/10.1007/s10639-020-10383-1
[52] S. Soury-Lavergne, "Duos of Digital and Tangible Artefacts in Didactical Situations," *Digit. Exp. Math. Educ.*, vol. 7, no. 1, pp. 1–21, 2021, https://doi.org/10.1007/s40751-021-00086-8
[53] R. M. Branch, *Approach, Instructional Design: The ADDIE*, vol. 53, no. 9. 2009. https://doi.org/10.1007/978-0-387-09506-6
[54] I. J. S. Vina Serevina, Sunaryo, Raihanati, I Made Astra, "Development of E-Module Based on Problem Based Learning (PBL) on Heat and Temperature to Improve Student's Science Process Skill," *TOJET Turkish Online J. Educ. Technol. –*, vol. 17, no. 3, pp. 26–36, 2018.
[55] Asmianto, M. Hafiizh, D. Rahmadani, K. Pusawidjayanti, and S. Wahyuningsih, "Developing Android-Based Interactive E-Modules on Trigonometry to Enhance the Learning Motivation of Students," *Int. J. Interact. Mob. Technol.*, vol. 16, no. 2, pp. 159–170, 2022, https://doi.org/10.3991/ijim.v16i02.27503
[56] Setiyani, D. P. Putri, F. Ferdianto, and S. H. Fauji, "Designing a digital teaching module based on mathematical communication in relation and function," *J. Math. Educ.*, vol. 11, no. 2, pp. 223–236, 2020, https://doi.org/10.22342/jme.11.2.7320.223-236
[57] N. Dahal, N. K. Manandhar, L. Luitel, B. C. Luitel, B. P. Pant, and I. M. Shrestha, "ICT tools for remote teaching and learning mathematics: A proposal for autonomy and

engagements," *Adv. Mob. Learn. Educ. Res.*, vol. 2, no. 1, pp. 289–296, 2022, https://doi.org/10.25082/AMLER.2022.01.013
[58] A. Barana, M. Marchisio, and M. Sacchet, "Interactive feedback for learning mathematics in a digital learning environment," *Educ. Sci.*, vol. 11, no. 6, 2021, https://doi.org/10.3390/educsci11060279
[59] H. H. Batubara, M. S. Sumantri, and A. Marini, "Developing an Android-Based E-Textbook to Improve Learning Media Course Outcomes," *Int. J. Interact. Mob. Technol.*, vol. 16, no. 17, pp. 4–18, 2022, https://doi.org/10.3991/ijim.v16i17.33137
[60] S. Papadakis, M. Kalogiannakis, and N. Zaranis, "Improving Mathematics Teaching in Kindergarten with Realistic Mathematical Education," *Early Child. Educ. J.*, vol. 45, no. 3, pp. 369–378, 2017, https://doi.org/10.1007/s10643-015-0768-4
[61] I. Katsaris and N. Vidakis, "Adaptive e-learning systems through learning styles: A review of the literature," *Adv. Mob. Learn. Educ. Res.*, vol. 1, no. 2, pp. 124–145, 2021, https://doi.org/10.25082/AMLER.2021.02.007

8 Authors

Tri Nopriana, M.Pd is a PhD student at the Department of Mathematics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. She serves as a Lecturer at Department of Mathematics Education, Universitas Swadaya Gunung Jati, Cirebon, Indonesia. Her main research interests include digital learning and mathematics education (email: trinopriana@upi.edu).

Prof. Dr. H. Tatang Herman, M.Ed is a Professor at the Department of Mathematics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. His main research interests include digital learning and mathematics education (email: tatangherman@*upi*.edu).

Dr. Bambang Avip Priatna Martadiputra, M.Si is an Associate Professor at the Department of Mathematics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. His main research interests include statistics and mathematics education (email: bambangavip@*upi*.edu).

Article submitted 2022-07-29. Resubmitted 2022-11-26. Final acceptance 2022-12-01. Final version published as submitted by the authors.