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Exploring the Characteristics of Digital Pedagogy Model for Developing Computational Thinking in Mathematical Problem Solving

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ABSTRACT

Challenges in the 21st century are increasingly complex, technology is developing rapidly and competition is getting tougher. Therefore we need quality human resources that can keep up with and anticipate the times. The use of technology involves computational thinking (CT) skills which are closely related to the problem-solving process. The stages in computational thinking are part of mathematical thinking, meaning that learning mathematics can support students' CT skills. Through the development of digital pedagogical models in CT integrated mathematics learning, it can improve problem-solving skills. This research uses design based implementation research with 4 phases including; preliminary research, prototyping, results, and design principle. The participants were 28 grade 8 junior high school students who took part in two rounds of experiment in direct CT activities and digital CT activities. In this paper, we present an iterative mathematical problem-solving process in the digital pedagogy model. The computational task, environment, tool and practices were iteratively improved over two rounds to incorporate CT effectively in mathematics. The results from CT environment demonstrated that direct CT activities are more effective than digital CT activities in mathematical problem-solving. Based on empirical research, we summarize the characteristic of the digital pedagogy model from computational tasks, computational environment and tools, and computational practices in mathematical problem solving.

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A. INTRODUCTION

In facing 21st-century learning, everyone must have critical thinking skills, knowledge and abilities of digital literacy, information literacy, media literacy and mastery of information and communication technology (Li et al., 2020). According to the Research and Development Ministry of Education and Culture (2013), the 21st-century learning paradigm emphasizes the ability of students to find out from various sources, formulate problems, think analytically and collaborate and solve problems. It is part of the skill computational thinking, which is an essential skill in the 21st century (Nordby et al., 2022; Palts & Pedaste, 2020; Tsortanidou et al., 2019). These skills are closely related to the use of technology.

The use of technology that involves skills in computational thinking is a qualification aimed at the new century, thereby increasing awareness and interest in computer science (Tonbuloğlu & Tonbuloğlu, 2019). It is therefore important to introduce CT concepts at the school level (Aman Yadav et al., 2014). CT reflection started from thinking about the way computer scientists think, but in the modern world it does not only involve computer scientists but also becomes a fundamental skill that everyone needs to solve problems effectively (Palts & Pedaste, 2020). This means that CT skills must be applied to the school curriculum.

Computational thinking is a problem-solving process that makes it possible in such a way that computers along with other tools can be used to obtain solutions (Thiago S. Barcelos et al., 2018). This is also supported by Barr & Stephenson (2011) who formulate a deep problem-solving processcomputational thinking on several stages including; formulating problems, organizing and analyze data logically, abstracting data, algorithms, identifiying and analyze solutions, generalizing and transfer the process of solving problems in various kinds of problems. Computational thinking has the potential to significantly advance students' problem-solving skills and abilities (A Yadav et al., 2017). Therefore computational thinking in learning can help students to solve problems in everyday life.

Computational thinking is closely related to learning mathematics (T S Barcelos et al., 2018). In solving complex math problems it is important to follow the steps of solving the problem according to the stage of computational thinking. Some problems in mathematics can be solved in algebraic form and some can be solved using technology (Kallia et al., 2021). Solving problems using computer programs can solve faster and more math problems. Of course, modeling is needed which is an important part of the computational thinking. Computer-related logic can create a balance between theoretical learning mathematics and practical in informatics education (Kallia et al., 2021). The purpose of learning mathematics in schools is not only to teach mathematics in terms of knowledge and concepts, but also to enable students to solve problems through decomposition processes, investigate and recognize patterns, abstract, and create algorithms from these various elements of education computational thinking. The interconnection between mathematics and computational thinking depending on the topic and problem to be solved (Wilkerson, 2018).

Computer science has many roots in mathematics (Thiago S. Barcelos et al., 2018), therefore it is important to develop mathematics learning by linking activities computational thinking to students. According to Kallia et al. (2021) there are similarities between the problem-solving strategies used in learning mathematics and skill computational thinking, this can be seen from several mathematical thinking skills such as abstraction, decomposition, data collection, data analysis, pattern recognition and debugging.

The integration of CT into mathematics learning aims to create mathematical activities that serve as a context for using CT strategies and CT helps deepen mathematics engagement. The integration of CT into learning mathematics can be seen in pronlem solving activities with decomposition stages, using pattern recognition, using algorithmic thinking, and using modeling and abstraction of logical thinking in solving structured problems to be able to provide solutions to mathematical problems to other people and machines (van Borkulo et al., 2019). From the results of computational thinking research shows that there is a positive and significant correlation between learning mathematics, through activity coding can improve CT skills and improve students' performance in mathematics (Kurniasi et al., 2022).

Based on the results of a questionnaire on the perceptions of junior high school mathematics teachers in the city of Padang, regarding integration computational thinking in learning mathematics, 100% of teachers agree that today's students are important and need to practice/learn computational thinking on the grounds that CT trains students to think critically (33.3%), CT prepares students to face the demands of the times and technology (33.3%), CT trains skillsproblem solving students (17.6%), CT trains students to think logically, systematically and sequentially (17.6%), CT can strengthen students' understanding of a concept (5.9%), CT trains students' high-level skills (2.0%) and CT trains students to think creatively (2.0%).

However, the integration of CT in mathematics learning still has challenges that must be overcome including defining learning progress, curriculum, assessing student achievement, preparing teachers and ensuring access to technology in learning (Weintrop et al., 2021). The same thing was also conveyed by Hsu et al. (2018) that many teachers have been accustomed to teaching processes and methods for years, making it difficult for them to curricula and adopt new teaching content. This is also supported by research by Israel & Lash (2020) that teachers have a limited understanding of the types of CT activities appropriate to learning mathematics. Another obstacle to integrating CT in mathematics learning refers to the scarcity of infrastructure in schools (Reichert et al., 2020).

The difficulties faced by mathematics teachers in making learning activities/LKPD integrated with CT include difficulties in determining material or contextual problems that can be integrated with CT (33.3%), difficulties in implementing the programming (17.6%), difficulties in designing learning, such as how to make activities, how to make trigger questions (17.6%), teachers feel they are still beginners in CT and programming so they find it difficult to integrate CT into activities (13.7%), time constraints are felt to be lacking if learning is integrated with CT (9.8%), teachers do not understand the concept of composition in CT (5.9%), inadequate facilities and infrastructure (3.9%) and difficulties in finding inspiration or ideas on how to integrate CT in learning (2.0%).

So far, people still think that everything related to CT must use a computer, even though not all CT activities use a computer. CT activities can be differentiated into direct (non-digital) activities such as: hands on activity, unplugged coding and problem-solving activities using paper and pencil. Then digital CT activities that require technology to support problem solving. The technology used also varies, including computers, calculators, gadgets and so on. Very little research has focused on how CT can be explored in learning, this exploratory study can provide a foundation for demonstrating that a combination of hands-on activities and digital applications can provide meaningful experiences for students (Lavigne et al., 2020).

CT activities in learning most studies adopt project-based learning, problem-based learning, cooperative learning and game-based learning (Hsu et al., 2018). Most of the research focuses on training mathematical programming and computing skills, while some adopt a cross-disciplinary learning model that allows students to manage and analyze material from various disciplines computationally (Hsu et al., 2018). Therefore it is important to develop teacher skills in using technology and build thinking skills while developing the affective aspects of students known as digital pedagogy.

Learners are digital natives who grew up with digital technology (Sailin & Mahmor, 2018). The survey results of the Indonesian Child Protection Commission (KPAI) in 2020 show that 79% of students in Indonesia use gadgets. And 71.3 percent of students have gadgets. This means that the intensity of the use of technology for students is also getting higher and they are getting more familiar with things related to digital. Therefore, to keep pace with technological developments, pedagogical innovation is needed. Teachers need to improve students' 21st-century skills through pedagogical innovation so that students can use technology to learn content and skills so that they know how to learn, think critically, solve problems, use information, communicate, innovate and collaborate.

Based on observations and interviews with junior high school mathematics teachers in the city of Padang, it turns out that students still experience difficulties in solving math problems. So far, students are only fixated on solving problems based on existing procedural examples. Furthermore, when given non-routine math problems they have difficulty connecting calculations with theorems, students are unable to identify, recognize and develop patterns of relationships or equations to understand the data or strategies used to strengthen their ideas. From the observations of researchers in class and the results of students' answers in learning mathematics, generally junior high school students have not linked the meaning of the data that has been found and its implications. Students are unable to understand the problem, develop a sequence of steps towards an appropriate solution and have difficulty finding alternative steps in solving mathematical problems. One of the causes of the learning process in the classroom is theoretically fixated, the teacher does not provide opportunities for students to carry out mathematical activities, both direct activities and digital activities with the help of technology. This is also consistent with the results of research by Aminah et al., (2022) that it is important for technology-assisted activities in learning to encourage students to solve mathematical problems which are a component of computational thinking.

Learning mathematics requires learning devices that use technology to ensure that the work done has the right answers. Some math learning applications that can be used include Scratch, GeoGebra, code and micro:bit and many others. The applications in this learning are expected to be able to explore abilities of computational thinking learners. Of course, in learning mathematics, the application is only a tool to help explore the skills of students. The role of the teacher is very large in designing and framing assignments based on 21st-century skills. The teacher provides information and resources needed by students in completing student assignments. Therefore, teacher competence is needed based on science, technology and learning activities. Teachers need to be prepared to take advantage of advances in information technology to improve the quality of learning and have digital pedagogical skills. This is to prepare superior human resources, can think critically, creatively, be innovative, communicative, and be able to collaborate and solve problems (Toktarova & Semenova, 2020).

The framework links betweencomputational thinking and digital pedagogy developed by Tabesh, (2017) this is based on constructivism learning theory, that students build new knowledge from their thoughts, from the interaction of experience with previous knowledge. Papert develops the theory of constructivism, by adding the idea that learning is enhanced by building meaningful products by using computational thinking in problem-solving. To enrich and connect the CT stages, a model is needed as a conceptual framework that is used as a guide in conducting integrated mathematics learning computational thinking and arranged systematically to achieve learning objectives related to syntax, social systems, reaction principles and support systems.

In this case the digital pedagogical model is designed to be easy for teachers to apply and easy for students to use to be able to experiment numerically, geometrically, and procedurally by modeling and tracing simple cases while looking for plots, patterns, symmetries and so on. Therefore, this research purpose to develop a digital pedagogical model in integrated mathematics learning computational thinking to improve abilities problem solving students. This model will combine direct activities and activities with digital applications in solving problems related to mathematics learning materials in junior high schools.

B. METHODS

This research uses design-based implementation research with 4 phases including; preliminary research, prototyping, results and design principle characteristics based on Figure 1. In the preliminary research phase, we analyzed the literature, environment, and needs. Then the prototyping phase is carried out with two rounds of learning. Each round evaluates and revises the learning process that has been carried out. The researchers applied an existing design framework and principles to design iterative cycles of testing and redesign of mathematical computational thinking in practice. The experimental from an exercise in students worksheet about linier equation. The design expanded the exercise to serve as content for problem-solving. The content was continuously explored with Geogebra aplication. The researchers constructed a visual learning environment for CT practices belonging to CT direct activities (nonprogramming plugged domain) then CT practices in digital activities. Total participants in this study of 28 eighth grade students in junior high school in SMPN 25 Padang, as shown in Figure 1.

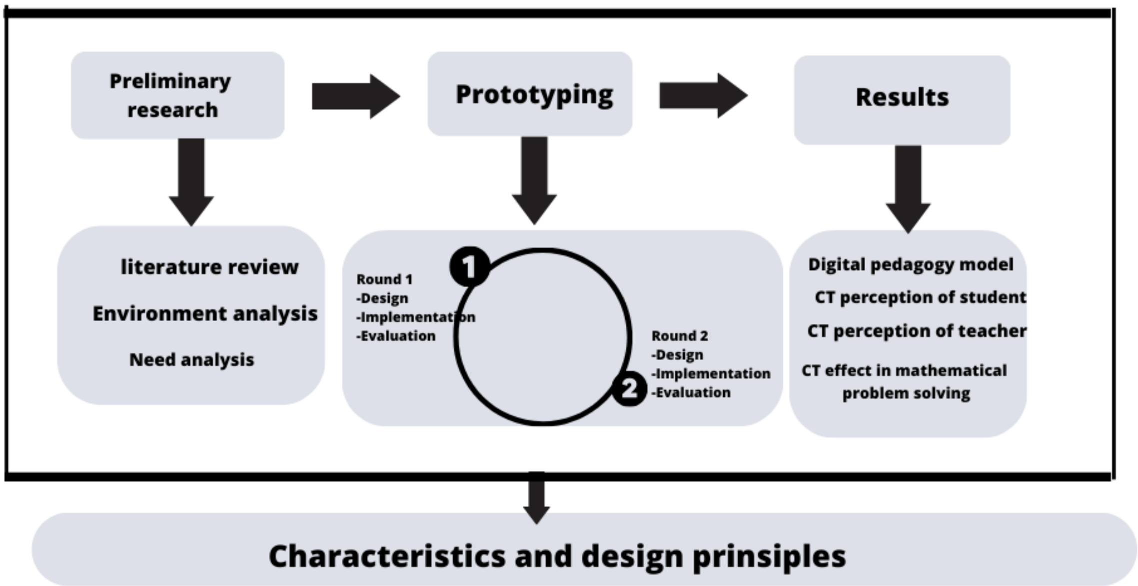

Figure 1. The design-based implementation research process

The experimental procedure was divided into two stages: preparitory instruction and formal instruction. During the preparotory instruction, the teacher evaluated participants prior knowledge and familiar with computational thinking activities. Following each of two round of formal instruction, the research and teaching teams discussed improvement. After revising the instruction and preparing the resources, the next round took place. Participant took CT questionnaires after each round of experiment.

C. RESULT AND DISCUSSION

1. Digital Pedagogy

The word pedagogy comes from the Greek word ‘paidagagos’ which means ‘a slave who takes children to school’, the traditional meaning of this term is far removed from the digital context. Meanwhile, the traditional understanding of pedagogy as an 'art' or 'science' needs to be reviewed in a new learner-centered teaching ecology. According to Rahayuningsih & Mukhtar (2021) pedagogy is a science that critically examines human essence and education as an effort to develop all aspects of human life through the educational process. Digital pedagogy is the use of digital technology in learning and teaching. In general, according to Santosa (2022) digital pedagogy is the process of delivering material, where activities occur in the classroom that involve technology. Digital pedagogy makes students active subjects in learning. According to (Väätäjä & Ruokamo, 2021) the digital pedagogical model consists of three dimensions, namely: (1) pedagogical orientation; (2) pedagogical practice; and (3) digital pedagogic competence.

Planning digital pedagogical activities begins by considering pedagogical orientation. Pedagogical orientation as the teacher's perception of what the learning process should be like. The pedagogical orientation depends on the goals of the curriculum, the role of the teacher in relation to teaching practice. Digital pedagogy is a learning paradigm based on digital technology while still paying attention to pedagogical principles so that students gain learning experience even though they are learning remotely. So, teachers are able to determine when to use digital tools and pay attention to their impact on learning.

2. Digital Pedagogy in Mathematics Learning

Digital pedagogy in learning mathematics is a learning paradigm that allows students to become active partners in discovering and developing their mathematical knowledge (Tabesh, 2017). Boaler & Staples (2008) suggest that smart computing devices can orchestrate media for digital pedagogy and influence the way people think and learn. The main key to developing innovative learning models associated with developmental psychology by Piaget (1966) into digital pedagogy in mathematics learning is to increase creativity. In the modern mathematics teaching and learning approach, students must become active partners and agents in the process of learning and problem-solving (Tabesh, 2017).

This modern approach to learning mathematics is more experimental and collaborative and is based on the principle of "learning by doing", and learning outcomes are authentic, because students are partners in the learning process. Students learn and develop their knowledge step by step through innovative and creative thinking, experience, and discovery, as well as through collaboration, and teamwork. Access to online information and resources has the potential to transform learning, and enable personalized and collaborative learning environments that go beyond schools and classrooms. Knowledge and skills are obtained from cognitive learning by empowering students for daily activities such as data analysis, reasoning, and problem-solving(Boaler & Staples, 2008).

3. Characteristics of Digital Pedagogy Model for Developing Computational Thinking in Mathematical Problem Solving

Digital teaching will revolutionize teaching and learning through the wide availability of learning resources. The reconstructed virtual learning experience underlies the change. Digital devices in teaching are integrated with the pace of changing times. Internet-related technologies, and mobile devices are now in classrooms (Toktarova & Semenova, 2020). In mastering digital pedagogy, a teacher must have the following competencies:

a. Digital Competence
   The most basic thing in using digital media is its use in teaching activities. Every use of the application, must be able to operate properly, so that it can be used properly by students.
b. Provision of digital learning materials and strategies
   A good teaching strategy is needed by a teacher to apply his competence. So that this becomes the basis for students to understand and understand the learning given.
c. Communication in the digital ecosystem
   Communication competence in delivering material and learning methods in digital classes will be different from conventional classes. There are several advantages to each of these methods. On the other hand, there are also deficiencies in digital and conventional learning methods that are technical and non-technical.
d. Digital Creative
   The use of digital media not only requires teachers to be more creative in using existing digital media as a means of interaction, but also broad insight into various applications and their use in teaching and learning activities.

Sintaxs digital pedagogy model for developing computational thinking in mathematical problem solving based on Tabel 1 and Figure 2.

Table 1. Sintaxs of Digital Pedagogy Model

No	Fase	Sintaxs	Description
1.	Fase 1	Context of problem	• Problem orientation • According to mathematics learning material
2.	Fase 2	Experience of CT activities	• Hand on CT activities • Digital CT activities
3.	Fase 3	Reflective of problem	• Investigation of math problem
4.	Fase 4	The action of the project	• Presenting project and work
5.	Fase 5	Evaluation	• Value analysis and actualization

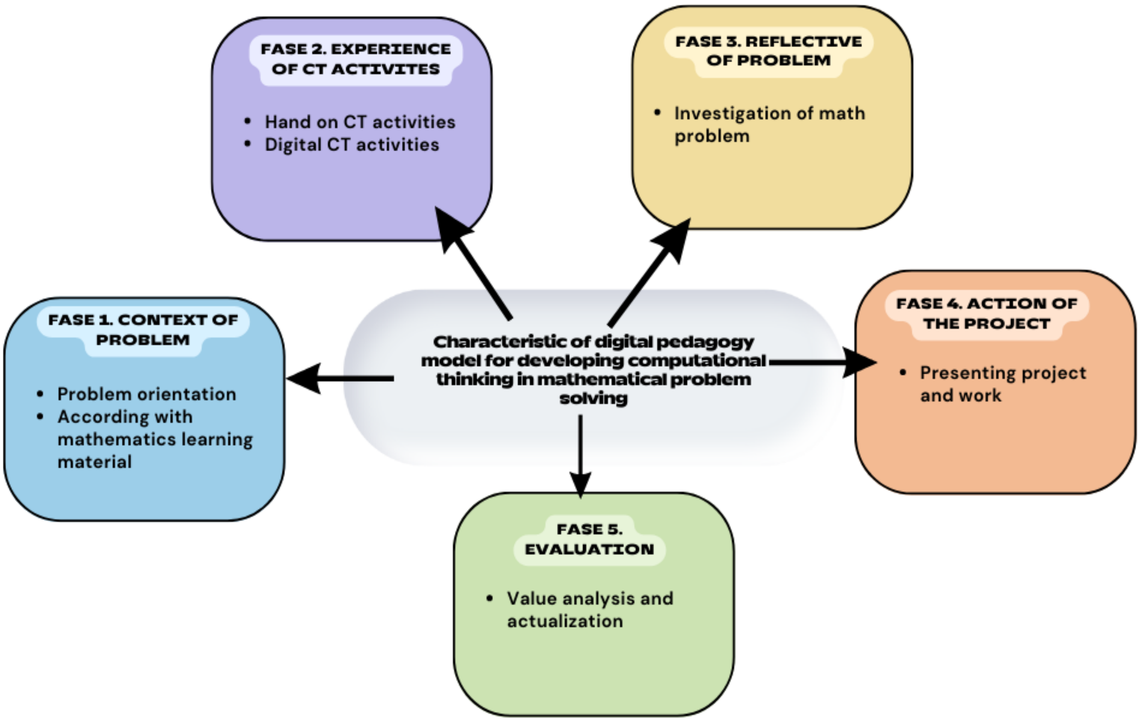

Figure 2. Characteristics of digital pedagogy model

4. Implementation of Digital Pedagogy Model for Developing Computational Thinking in Mathematical Problem Solving

a. Fase 1. Context of problem

The ramp is a path in the form of a field with a certain slope, as an alternative for people who don't use stairs. The ramp is an important feature of the building that wants to ensure inclusiveness for persons with disabilities who use wheelchairs. Many things need to be considered in ramp construction so that it is safe to use. First, the ramp must be strong enough to withstand the burden of people passing over it. Second, the surface of the ramp must have a texture in such a way that people who use it do not easily slip. Third, the width of the ramp must be appropriate so that there is enough space for people to pass by. And fourth, based on Figure 3. the slope of the ramp must be made in such a way that it is not too sloping or steep.

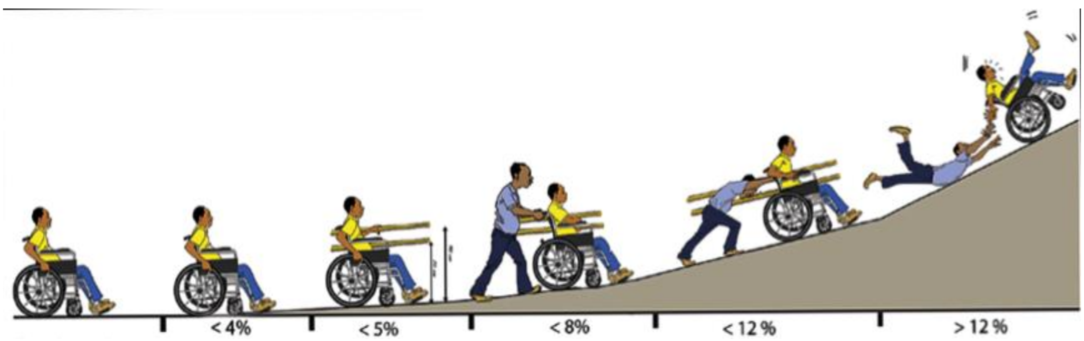

Figure 3. The slope of the ramp. source: https://hhot.cbm.org/id/card/jalur-landai

Table 2. International Slope Provisions

AREA	FUNCTION	SLOPE IN PERCENT	
		MAX	MIN
Streets & Drives		5%	1%
		8%	0.05%
Ramps		10%	1%
		15%	NA
Walkway approaches and entrances		4%	1%
		5%	0.5%
Services areas and collector walks		8%	0.5%
		10%	0.5%
Terrace and sitting areas		2%	1%
		2%	0.5%
Lawn area and playgrounds		3%	2%
		4%	0.5%

b. Fase 2. Experience of CT activities
Design a sketch of the terrace in front of the school with a certain slope so that it is safe for wheelchair users.
1) Decomposition
Students can decipher information related to the slope of the school's front porch so that it is safe for use by wheelchair users. At this stage students begin to design a suitable design by paying attention to the length and height of the terrace. And follow the tilt regulations internationally (based on Tabel 2). Student design of terrace school based on international regulation and safe for use by wheelchair users. Students can identify, recognize and develop patterns of relationships or equations to understand the data obtained. Students began to compare the sketches of the school terrace slope designs that were made whether they were safe for users of wheelchairs, stairs and pedestrians. By expressing ideas related to the design made. The teacher conveys the project that the students will carry out, namely building a miniature ramp. Small ramps are built with cardboard and cardboard boxes, and tested with marbles.
2) Abstraction
Students can understand from the data that has been found and its implications. Students begin to calculate the slope of the school terrace design they made, as shown in Figure 4.

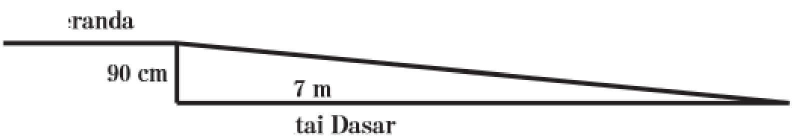

Figure 4. Slope of the school terrace

The image above, shows that the porch rises 90 cm above the ground level, and the walkway extends 7 m, or 700 cm, from the lip of the porch. The following equation can be used to calculate the slope of the road being built.

$$\text{Slope} = \frac{\textit{Change in line of vertical}}{\textit{Change in line of horizontal}} \tag{1}$$

$$\text{Slope} = \frac{90}{700} \approx 0{,}128 \tag{2}$$

Thus, because the road being built has a slope of less than 0.15, then it complies with the safety rules for using a wheelchair.

3) Algorithm
Students can understand and analyze problems, develop a sequence of steps toward an appropriate solution, and find alternative steps in solving problems. Students begin to analyze the problem, if the slope obtained from the calculation results is not safe for wheelchair users, what will they do? Student answers: Lengthen the wheelchair ramp so that the ramp is more sloping.

c. Fase 3. Reflective of problem
From the illustration of the problem regarding the slope of the road for wheelchair users. Students began to give arguments about the designs they designed in their groups. The results of students' critical thinking become a reflection of this problem. Then, students solve problem by using geogebra. Teacher give code number to the joint in the geogebra classroom, as shown in Figure 5.

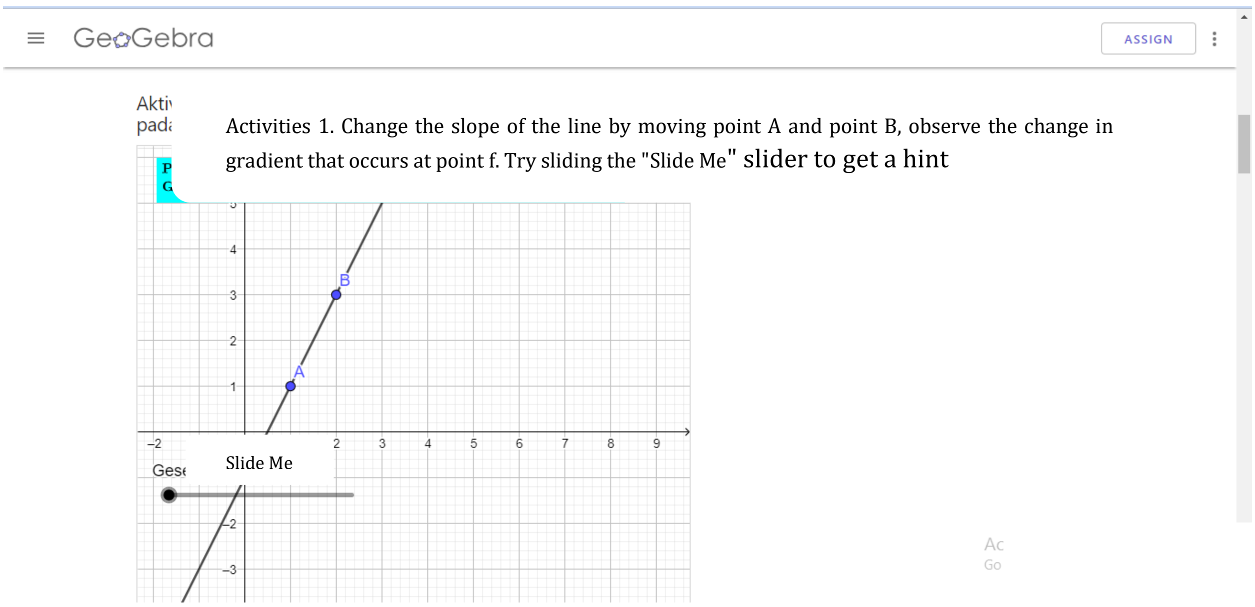

Figure 5. Student Activities in Geogebra

d. Fase 4. The action of the project
   Students display the results of the ramp design for the terrace in front of the school. And explain the length of the terrace, the height and the slope used. As well as the reasons for choosing a design both architecturally and aesthetically.
e. Fase 5. Evaluation
   At this stage students evaluate their investigations in the process they used in designing the school terrace ramp so that it is safe for wheelchair users. Based on CT direct activities and CT digital activities by using Geogebra, student are able to determine the gradient of a line.

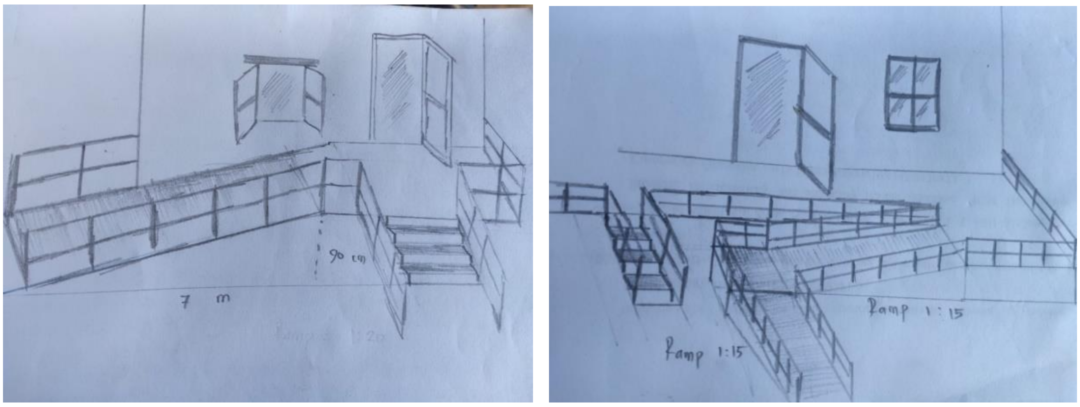

Figure 6. Design of school terrace

Based on Figure 6. students design of school terrace which is safe for wheelchair users. The next student practices another slope by using geogebra.

D. CONCLUSION AND SUGGESTIONS

Implementation of the digital pedagogy model in mathematics learning integrated with computational thinking, the first thing that must be done is to choose a mathematics learning topic that is related to CT. Then develop learning activities with CT stages. Learning activities can be carried out directly in the classroom and digital activities assisted by technology. In this research, the Geogebra Classroom application was used to support students' understanding of the mathematical problems given. The CT tools used can vary according to the context of the material chosen. Teachers can introduce various learning applications to support this digital pedagogy model. There are five phase of pedagogy digital model for developing computational thinking in mathematical problem solving; context of problem, experience of CT activities, reflection of problem, action of the project, and evaluation.

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