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Students' Digital Thinking Skills in Solving Mathematics Problems

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ABSTRACT
This study aims to describe the level of students' digital thinking skills in solving mathematics problems in terms of 21st – century digital skills, referring to the eight levels of digital competence by prioritizing the cognitive domain of students in their measurement. Data collection was carried out by data analysis and two-interviews with 20 students of class XI in Malang city as subjects in solving mathematics problems using digital technology. The results showed that the students' digital thinking skills were at levels 4, 5, and 6. There were no students who showed digital thinking skills at levels 7 and 8.

Keywords: *Digital Competence, Digital Thinking, Problem Solving.*

1. INTRODUCTION

Digital competence has been a critical concept in discussing the skills and understanding that humans must possess. These competencies include information management, collaboration, communication and sharing, content and knowledge creation, ethics and responsibility, evaluation and problem solving, and technical operation [1]–[6]. The challenges that arise in the world of education today require educators and students to be more competent in intelligence, skills, and thoughtful use and control of digital technology. Besides, along with the changes in the way education works, 21st – century skills such as seeking and evaluating information, solving problems, exchanging information, or developing ideas in a digital context are deemed essential.

In 21st century learning, digital technology is transforming traditional learning and mobilizing the skills needed in an emerging digital environment. It implies digital competence mastery becomes the essential skill that must be had by every human. As an era based on ICT, students can be a productive digital generation with the best 21st – century digital skills. Furthermore, the digital skills of the 21st – century are explained as skills to think digitally. This definition's key elements focus on skills, desired attitude for complex problem solving with employability of computers, and habits [7], [8].

Digital thinking often raises the question, why not learn thinking skills that can be widely applied? Meanwhile, digital thinking skills will develop essential competencies in the digital [9], leading to real-world problem aspects, designing the system, comprehending human behavior, and abstraction as its essence [10]. [10], [11] revealed that digital thinking could motivate students to create new tools and foster creativity so that students are not only consumers of knowledge. Therefore, we need to put student creativity at the digital transition center as the most critical ability to survive in the digital era [12].

Current innovation depends on technology and how it interacts with humans, solving problems, and needs and challenges [11]. Many experts have compiled the 21st-century digital capabilities [1]–[5], that describes the digital thinking skills of the 21st-century. In this study, researchers wanted to know the ability to think digitally seen from students' level of digital competence. Digital competence involves a wide range of skills, including cognitive and emotional skills and sociological knowledge, to effectively use the digital environment [13]. With this competency, Instefjord (2015) highlights the critical and reflective use of technology when

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students build new knowledge in developing critical thinking skills. [14] identified twelve different areas that encompass digital competence composing knowledge, skills, and attitudes.

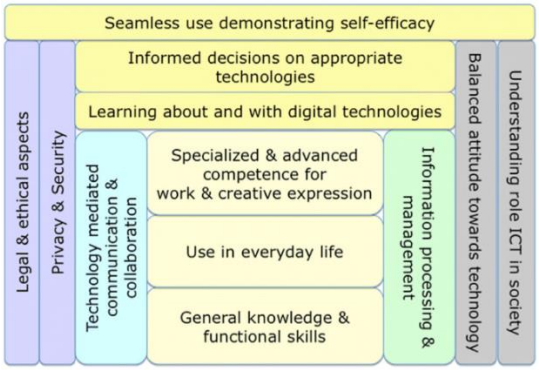


Figure 1 Area of Digital Competence: Experts' Collective View [14]

[4] created a digital competence framework by revising it from four levels to eight proficiency levels by listing cognitive domains that students might reach. The descriptions at each level contain knowledge, skills, and attitudes, explained by a single description. The description for each level is as follows:

Table 1 Level of Digital Competence Based on [4]

Level in DigComp	Complexity of Task	Autonomy	Cognitive Domain
1	Simple task	With guidance	*Remembering*
2	Simple task	Autonomy and with guidance where needed	*Remembering*
3	Well-defined and routine task, and straightforward problems	On my own	*Understanding*
4	Tasks, and well-defined and non-routine problems	Independent and according my needs	*Understanding*
5	Different task and problems	Guiding others	*Applying*
6	Most appropriate tasks	Able to adapt to others in a complex context	*Evaluating*
7	Resolve complex problems with limited solutions	Integrate to contribute to the professional practice and to guide others	*Creating*
8	Resolved complex problems with many interacting factors	Propose new ideas and processes to the field	*Creating*

Based on [15] (p. 47), problem-solving abilities can be approached from digital competence and characteristics of digital thinking skills. Digital thinking skills can be raised through the application of digital competencies and digital competence can be applied when students have the ability to think digitally. The following are the characteristics of students' tasks and problems at each level of students' digital thinking abilities which is derived based on the level of the student's digital competence in accordance with the explanation in [15].

Level 8: Students solve complex problems with many interacting factors so that they can propose new ideas or processes to the field

Level 7: Students solve complex problems with limited solutions that integrate to contribute to professional practice and to guide other students

Level 6: Students can do appropriate tasks and can adapt to others in complex contexts

Level 5: Students can work on different assignments and problems and can guide other students

Level 4: Students can work on defined and non-routine tasks and problems independently and are provided with guidance according to their requests and needs

Level 3: Students can do well-defined routine tasks and straightforward problems by trying on their own

Level 2: Students can do simple tasks with guidance according to their needs

Level 1: Students can solve problems in the form of simple tasks with teacher guidance

This research is necessary because the demands of having digital competence are for students and educators, such as the framework developed by DIGICOMP for citizens' work [16] and the TPACK model [17] as bellow.

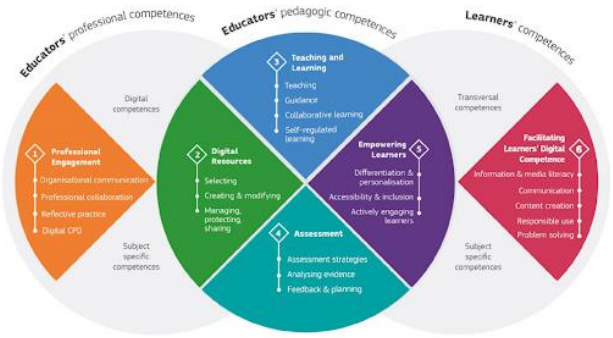


Figure 2 European DigiCompEdu Framework for Teacher [16]

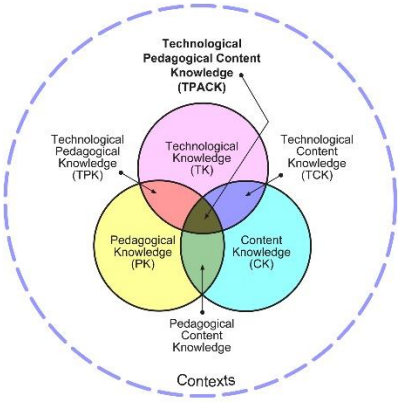


Figure 3 TPACK Model [17] (image from http://tpack.org)

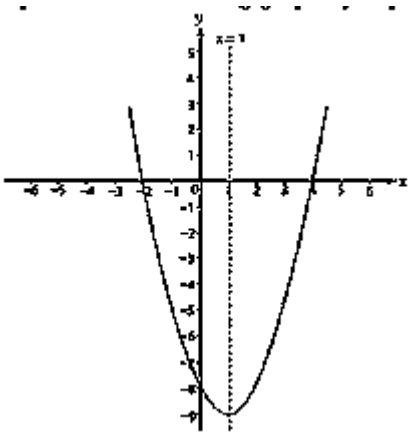
Through this research, researchers tried to describe students' digital thinking skills through assignments and problem solving. If we view problem-solving as a cognitive and learning activity, then we will get information processing. Problem-solving includes understanding problems, compiling plans, implementing plans, and reviewing [18]. [19] explains that giving assignments by including problems requires the ability to relate previously owned information to new ways by the students themselves to do it. When it is related to the demands of digital skills that students must have, students must have the ability to connect previously owned information in new ways with digital technology.

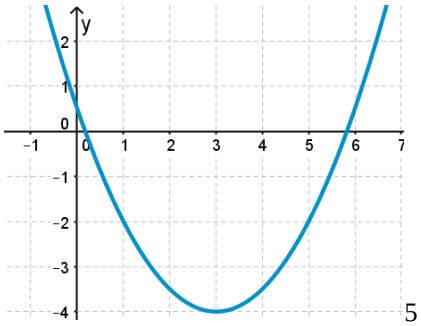
This research aims to describe the characteristics of the level of students' digital thinking skills. Digital thinking in this study is assumed to be a mental process that a person uses to generate new ideas or processes to solve problems in the field. The new ideas or processes in this definition are the student's thoughts for completing tasks or solving problems. The student shows the ability to think digitally at level 1 when he/she can do simple tasks given with his/her teacher guide. Then, level 2 when he can do simple tasks with guidance when needed, at level 3 when he can do well – defined routine tasks and straightforward problem by trying it yourself, and so on according to the level of students' digital thinking ability.

2. METHOD

This research uses a qualitative approach that aims to identify the characteristics of students' digital thinking level. The research subjects are 20 students from groups with high, medium, and low abilities in mathematics by teachers' nomination and good communication skills. Data collection is based on the results of tasks and interviews. The tasks based – interviewed is an open task that has different solutions and methods. The following are the types of tasks that will be given to determine students' digital thinking skills.

Table 2 Tasks of Digital Thinking

	Tasks	LDT
1.	Which of the following is the quadratic equations' form? a. $3x^2 = 27$ b. $-5y^2 + 2y + 1 = 0$ c. $z^2 + 4z - 2 = 6$ d. $0p^2 + p - 2 = 0$ e. $8q^2 + 4q - 2 \leq 6$ f. $r^2 + ry + 1 \geq 0$ g. $3s - 7 = 0$ h. $2(t^2 - 2t) = 5$	**1/ 2**
2.	What is the definition of quadratic equations?	**1/ 2**
3.	Represent the following graph by a quadratic equation. 	**3**
4.	Give an example of a non-quadratic equation, then explain why it is not a quadratic equation.	**3**
5.	Given some quadratic equations as follows: a. $x^2 + 4x + 2 = 0$ b. $2x^2 + 4x + 2 = 0$ c. $x^2 + 2x + 4 = 0$ d. $-x^2 = 2x + 1$ e. $5x^2 + 6x + 1 = 0$ f. $5x^2 + 2x + 1 = 0$	**3**

	Tasks	LDT
	From those equations, which ones have real roots and which ones have imaginary roots?	
6.	Make a simple summary of the quadratic equations and its root!	**4**
7.	Write down a general procedure for graphing a quadratic equation.	**4**
8.	Identify the advantages and disadvantages of solving quadratic equations with the factoring method, completing quadratic and quadratic formulas.	**4**
9.	What do you understand about quadratic equations?	**4**
10.	Find the solutions of this quadratic equations. a. $5x^2 + 13x + 6 = 0$ b. $x^2 + 6x + 5 = 0$	**5**
11.	Find the quadratic equations from the graph below.  5	**5**
12.	Is the following statement is true? Explain. "If the quadratic equation $ax^2 - 4x + 10 = 0$ have roots x_1 and x_2 with $x_1.x_2 = 5$, then $x_1 + x_2 = -2$."	**6**
13.	Determine the roots of the quadratic equation $2x^2 - 3x - 5 = 0$ in two ways. Which method is easier to use? Why?	**6**
14.	Create a quadratic equation where the equations' roots are x_1 and x_2 and a new quadratic equations whose roots are three more than the roots of the first quadratic equations.	**7/ 8**

All subjects will be given the same tasks. When the subject works on a given task, the researcher makes observations and brief interviews to clarify what steps the subject is doing and checks the results of the subject's task. When a subject has difficulty in a given task, the researcher will provide assistance in accordance with the predetermined autonomy. If after being given assistance according to their autonomy the student feels that they are unable to understand or are unable to continue working on the assigned task, then the student will be given another tasks that is similar to the first task (as data triangulation). The students' work is analyzed by identifying the correct answers and then examining the aspects of digital competence that students solve. Data were analyzed by the constant comparison method [20], [21]. If the student is still unable to do the second similar task (as in the initial conditions), then the student is considered to be at the digital thinking level according to his last assignment. In other word, the student level is estimated by applying qualitative analysis methods to determine students' level of digital thinking.

3. RESULT

A total of 20 students were selected as research subjects consisting of 9 male students and 11 female students. However, researchers only took 14 students who presented the best data to determine the characteristics of students' digital thinking abilities. For the six subjects, their data can't be used because all of them have problem in using internet connection when the task was given. Two of them can't join the task on time, and the rest lost connection in the middle of tasks. So, researcher choose not used their data for the validity result data. Then each subject was given a code name pseudonym. Code for the subject's pseudonym is adjusted to the subject's mathematical ability, R for subjects with low math ability, S for medium math ability, and T for high math ability. The number after the subject code indicates the-ith subject. The following is data from all samples.

Table 3 Data of Sample

No.	Pseudonyms	Gender	LDT
1.	R1*	Male	-
2.	R2	Male	3
3.	R3	Female	4
4.	R4*	Male	-
5.	R5	Female	3
6.	R6	Female	3
7.	S1*	Female	-
8.	S2	Female	4
9.	S3*	Male	-
10.	S4	Male	3
11.	S5	Male	4
12.	S6	Female	5
13.	S7*	Female	-
14.	S8	Male	6
15.	T1	Female	5
16.	T2	Female	6
17.	T3*	Female	-
18.	T4	Female	6

Table 3 Data of Sample

No.	Pseudonyms	Gender	LDT
19.	T5	Male	6
20.	T6	Male	5

Note: *is code for subjects that are not include in the descriptions

The following will be presented some of the math problem-solving results by the subject at each level that appears and its characteristics in Table 4.

Table 4 Analysis of Research Result

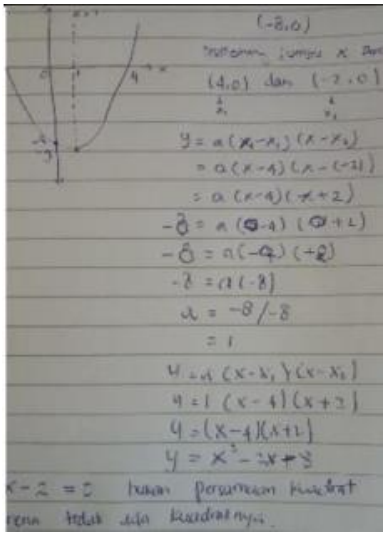
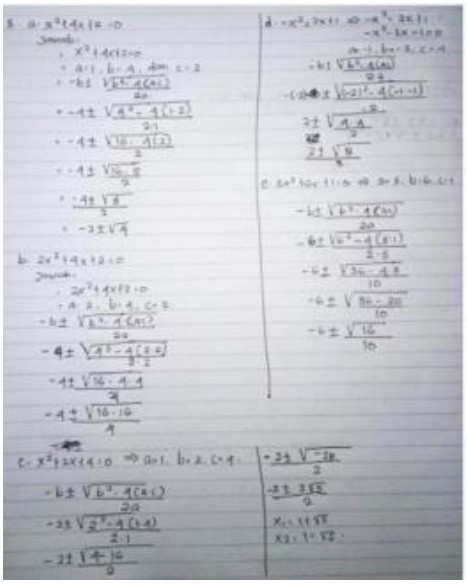
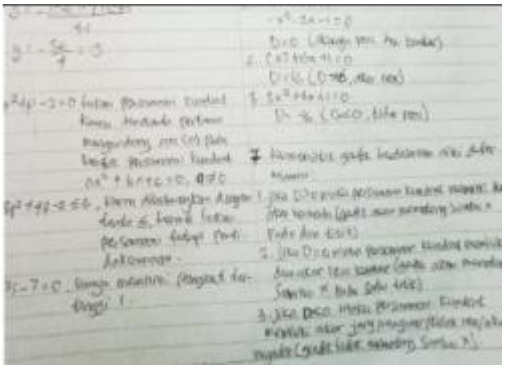
Subject	Research Result
R2	R2 is a male student with low math ability based on the class teacher'' nomination. In this study, R2 shows level 3 digital thinking skills. It'' indicated by R2'' ability when solving problem-solving tasks given with the help of digital technology. R2 is quite fluent in finding the material needed and only asks two preliminary questions regarding the search results. The first question is about whether the answers to assignments 1 and 2 that he is working on are correct, and the second is about whether the material he is reading and the next assignment is appropriate. When confirmed with simple questions by the researcher, R2 can tell him the information he needs to answer the questions and explain how he found the material needed. However, R2 failed to complete all tasks at the third level (can work on questions but does not answer the final question).  

Table 4 Analysis of Research Result

Subject	Research Result
S2	S2 when solving problem-solving tasks given with the help of digital technology. S2 is quite fluent in finding the material needed and can answer non routine questions asked with the help of a few pointers when he asks for them. When confirmed by the S2 researcher, he can describe what information needs he needs to answer questions and create keywords that suit his needs. 
S6	S6 is a female student with moderate math ability based on a class teacher nomination. In this study, S6 shows the ability to think digital level 5. It'' shown by the ability of S6 when solving problem-solving tasks given with the help of digital technology. S6 is not only fluent in doing assignments, but it has also begun to be able to help her friends solve problems by showing her how to do them herself or guiding her friends to find the best material needed to solve the problem by themselves (notifying the search keywords for information, where the best sources are found). Brief confirmation with the subject indicates that the subject can find the information necessary for him or her and provide assistance to friends by showing how to access or find the required information.
T5	T5 is a male student with high math ability based on a class teacher nomination. In this study, T5 shows the ability to think digital level 6. It'' indicated by the ability of T5 when completing problem-solving tasks given with the help of digital technology. Besides being fluent and able to assist his friends, T5 is also able to assess the most needed information needs, adjust the search strategy to the information needs to be needed, explain well how to access data, information and content that best suits what is needed, can choose a strategy for carrying out tasks with well, and also vary their information-seeking strategies.

In this study, researchers have not found subjects with basic digital thinking skills, namely level 1 or 2, or very expert levels, namely level 7 or 8. However, researchers still write down these levels' characteristics based on the description and type of task in each level. Based on the data obtained above, the researcher based the eight levels of students' digital thinking skills in solving problems to describe their characteristics.

Table 5 Characteristics of The Digital Thinking Level

Level	Characteristics of The Digital Thinking Level
8	At a high level or specialized, subjects can solve complex problems by involving many interacting factors related to searching, searching and filtering data, information, and digital content to complete a given task.

Table 5 Characteristics of The Digital Thinking Level

Level	Characteristics of The Digital Thinking Level
	Besides, they are also able to propose new ideas and processes for solving a problem.
7	The subject can create solutions to complex problems of limited definition related to browsing, searching and filtering information data and digital content at a high skill level. Besides, they can also integrate their knowledge to contribute to knowledge practices and guide others in browsing, searching and filtering data, information, and digital content.
6	At this advanced expert level, subjects can assess their information needs, select appropriate strategies for finding the most appropriate data, information and digital content, explain how to access and vary their search strategies for themselves and others in complex contexts.
5	At the expert level, the subject can guide friends or colleagues, respond to information needs, implement searches and show how he accesses data, information and digital content and proposes his search methods.
4	At this intermediate level, the subject can independently solve problems that are obvious and not routine. Besides, they can describe their own needs for information, organize and explain how to access data retrieval, information and digital content.
3	At this initial intermediate level, the subject can independently solve it directly by explaining the information needed, carrying out straightforward and routine searches to find and explaining how to access data, information and digital content.
2	At the basic level, by assisting as needed, subjects can identify the information needed, find and know how to access data, information and digital content, and identify simple search strategies.
1	At a basic level, with assistance, subjects can identify the necessary information, find and know how to access data, information and digital content, and identify simple search strategies.

4. DISCUSSION AND CONCLUSION

The characteristics at each level of digital thinking skills are shown in table 3 above. This leveling can be assumed as one of the specific domains of learning mathematics in the classroom when students take part in learning activities, both in task work and problem-solving. This leveling is based on students' digital competence, which is still rarely discussed [22]. Digital competence is a concept that describes technology-related capabilities that are often used normatively and to represent goals to be achieved. At this level, the researcher believes that students' digital thinking skills cannot be described only by providing a level based on student responses to a given problem-solving task without paying attention to other perspectives.

Students in the class are rarely invited to take advantage of digital technology in learning. They will only do the assignments according to what is described by the teacher and what is stated in the textbook. Now, because of the times and the environment'' demands, distance learning models are the wisest choice to implement. Therefore, it is essential to know students' digital thinking skills.

By knowing the level of students' digital thinking skills, teachers will be able to anticipate and be able to transfer knowledge according to their level as well as learn digital competencies such as technical skills, information management, communication, collaboration, creativity, critical thinking, and problem-solving [1]–[3]. If students can only do simple tasks with the teacher'' guidance, they can be categorized as students with level 1 digital thinking skills. If they can do simple tasks with teacher guidance when needed, they can be categorized as students with level 2 digital thinking skills. So, until students can create solutions to solve more complex problems by linking various factors that may be involved and propose new ideas and processes, they can be categorized as students with level 8 digital thinking skills.

This research is only one approach to assessing, identifying, or clarifying students' digital thinking in solving mathematical problems based on their digital competencies. The study of digital thinking or digital capabilities has many limitations as a multi-faceted phenomenon that involves technology and individual readiness and abilities. Researchers suggest further research related to students' digital thinking skills associated with age and differences in the given task model. Finally, hopefully, this research can stimulate other people to continue research, verify, modify, or apply it.

AUTHORS' CONTRIBUTIONS

Nila Kartika Sari, Mega Teguh Budiarta, Kardiana Metha Rozhana

N.K.S. and M.T.B. understand and develop research ideas. N.K.S., M.T.B., and K.M.R. verify research methods. N.K.S. and K.M.R. carry out data collection and analysis of research results in the field. M.T.B. encouraging N.K.S. to investigate certain aspects and monitor findings that arise during research. All authors discussed the results and contributed to the final manuscript.

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