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Creativity in Mathematics: Mathematical Reasoning Ability of Indonesian Students and Solution Recommendation

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ABSTRACT

Background: Developments in the 21st century affect rapid changes in industry and people's lifestyles. Some experts have concluded that creativity is one of the competencies needed today. However, several studies show problems in the development of students' creative abilities in schools, one of which is from teacher competencies and students' low mathematical reasoning abilities. **Objectives:** This paper contributes to an overview of actual problems related to the quality of students' mathematical reasoning abilities and solution recommendations. **Design:** The method used in this study is a qualitative approach to analysing the quality of reasoning abilities using the Lithner framework with three categories of quality mathematical reasoning abilities and using teacher interviews to confirm student reasoning test results. **Setting and participants:** The sample used in this study was 27 junior high school students in Cianjur Regency, Indonesia, and one of the mathematics teachers in the same school. **Data collection and analysis:** The instrument used in this study was a reasoning ability test and an interview transcript. **Results:** The study indicates that most students have very low mathematical reasoning abilities. In addition, the results of interviews with mathematics teachers illustrate that the main problem is students' low basic mathematical abilities, especially in arithmetic operations. **Conclusion:** The author's analysis shows that there are three main problems with students' low reasoning abilities, namely, low students' cognitive abilities, lack of mathematical challenges, and students' low motivation to learn mathematics. Based on study results, this paper also presents recommendations for solutions related to low reasoning ability.

Keywords: mathematical reasoning; creativity; mathematics creativity

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Criatividade em matemática: Capacidade de raciocínio matemático de estudantes indonésios e recomendação de soluções

RESUMO

Antecedentes: Os desenvolvimentos no século 21 afetam mudanças rápidas na indústria e no estilo de vida das pessoas. Alguns especialistas concluíram que a criatividade é uma das competências necessárias hoje. No entanto, vários estudos mostram que existem problemas no desenvolvimento de habilidades criativas dos alunos nas escolas, um dos quais é de competências dos professores e baixa capacidade de raciocínio matemático dos alunos. **Objetivos:** Este artigo contribui para uma visão geral dos problemas atuais relacionados à qualidade das habilidades de raciocínio matemático dos alunos e recomendações de soluções. **Projeto:** O método usado neste estudo é uma abordagem qualitativa para analisar a qualidade das habilidades de raciocínio usando a estrutura de Lithner com três categorias de habilidades de raciocínio matemático de qualidade e usando entrevistas com professores para confirmar os resultados do teste de raciocínio do aluno. **Cenário e participantes:** A amostra utilizada neste estudo foi de 27 alunos do ensino fundamental em Cianjur Regency, Indonésia, e um dos professores de matemática da mesma escola. **Coleta e análise dos dados:** O instrumento utilizado neste estudo foi um teste de capacidade de raciocínio e uma transcrição da entrevista. **Resultados:** Os resultados deste estudo indicam que a maioria dos alunos tem habilidades de raciocínio matemático muito baixas. Além disso, os resultados das entrevistas com professores de matemática ilustram que o principal problema são as baixas habilidades matemáticas básicas dos alunos, especialmente em operações aritméticas. **Conclusão:** A análise do autor mostra que existem três problemas principais com as baixas habilidades de raciocínio dos alunos, a saber; habilidades cognitivas baixas dos alunos, falta de desafios matemáticos e baixa motivação dos alunos para aprender matemática. Este artigo também apresenta recomendações para soluções relacionadas à baixa capacidade de raciocínio com base nos resultados do estudo.

Palavras-chave: raciocínio matemático; criatividade; criatividade matemática

INTRODUCTION

The exponential development of technology and science in the 21st century has led to sustained progress in every field of life (Cai & Leikin, 2020; Leikin & Elgrably, 2020; Lu & Kaiser, 2022). These developments demand reliable competence. Today, researchers, educators, policymakers, and industry agree that creativity is one of the skills most needed in the 21st century. They argue that creativity can provide better opportunities for success in an era of global challenges and exponential environmental changes, both in terms of career preparation, economy, and welfare (Bicer et al., 2021; Cai & Leikin, 2020; Hafizi & Kamarudin, 2020; Leikin & Elgrably, 2022; Newton et al., 2022).

Traditionally, creativity is often associated with art. The Oxford Dictionary defines skill as “the use of imagination or original ideas, especially in the production of a work of art” (Bicer et al., 2021; Munakata et al., 2021). In addition, traditional thinking also assumes that creativity is innate and permanent (Bicer et al., 2021; Newton et al., 2022). However, many researchers today have emphasised the importance of developing creativity in individuals in various domains, such as science, technology, engineering, and mathematics (STEM), meaning that there is a shift in the traditional understanding of the domain of creativity from more specific content as an innate characteristic to a set of skills that can be developed in each individual (Bicer et al., 2021).

Discussing creativity as an important skill individuals have is inseparable from the role of schools in developing creativity in the curriculum and learning process. Several things need to be confirmed, and some cause obstacles in the application of creativity in schools, including differences in understanding regarding whether creativity is a general domain or a specific domain (Bicer et al., 2021; Milgram & Hong, 2009), differences of opinion regarding whether creativity is a process or a result (Haavold & Birkeland, 2017; Joklitschke et al., 2022; Leikin & Elgrably, 2022), and the difficulty of compiling instruments that can measure student creativity in certain content other than giving assignments based on problem solving (Haavold & Birkeland, 2017; Leikin & Elgrably, 2022; Schindler et al., 2016). Apart from the mentioned obstacles, others are related to those three general hindrances.

The debate about whether creativity is a general or special domain has been going on for a long time, and now researchers have agreed that creativity is a specific domain. We said previously that currently, researchers have emphasised the development of creativity in domains included in STEM (Bicer et al., 2021). Currently, there are many studies regarding the development of creativity in mathematical content, commonly called creativity in mathematics. However, Haavold and Birkeland (2017) stated that some teachers think creativity is a general domain but agree that it is not fixed and can be developed through learning. Regarding the development of creative processes in schools, teachers argue that creativity is individual, including creativity in mathematics, as the assessments of high school students in various countries should be. Chinese, French, English, Indian, Japanese, South Korean, and Turkish students must take tests to go to the following study levels that are based mostly on students' memorisation rather than creativity (Bicer et al., 2021; Haavold &

Birkeland, 2017; Milgram & Hong, 2009). As a result, applying creativity to mathematics at school is quite challenging due to the high cognitive load, the complexity of evaluating each individual, and the goals of institutions and students in continuing to a higher level.

The following statement concerns the teacher's lack of understanding regarding whether creativity is a process or a result. Once again, Haavold and Birkeland (2017) provide that teachers view creativity as related to “how to do something”, meaning that teachers think that creativity is a process, not a result. There are several opinions related to mathematical creativity as a process. For some people, creativity as a process is a thought behind efforts to solve mathematical problems, whether it leads to a solution or not (Newton et al., 2022). In addition, the perspective of creativity as a process can be seen from the goals of creativity in general, that individuals are said to be creative if they can use their knowledge in new situations flexibly and originally so that creativity is closely related to a method or process (Leikin & Elgrably, 2022). The obstacles that occur regarding this statement are found in a study conducted by Haavold & Birkeland (2017). The teachers agree that students must have mathematical creativity skills, but not in their classes. Once again, the problem of workload and the characteristics of individual creativity cause obstacles to applying creativity in mathematics learning.

The third statement is related to the instrument for measuring mathematical creativity and its relation to problem-solving methods, which is closely related to the previous statement, that creativity is a process. Based on the teacher's perception in Haavold and Birkeland (2017), creativity in the classroom is related to the creative assignments given. According to the teacher, the characteristics of creative tasks are tasks that have many solutions. In its application, there is no consensus about the types of math tasks that can encourage the development of creativity and make it possible to assess creativity (Leikin & Elgrably, 2020). Based on the teacher's opinion and the study by Leikin and Elgrably, there is currently no valid type of task to measure student creativity. Still, this information confirms that creativity is closely related to problem-solving-based assignments. Haavold and Birkeland (2017) provide facts in the field that although teachers agree that creativity is closely related to the creative assignments given, until now, the focus of learning mathematics in schools is still on rule-based computing with sequences of concepts, skills, strategies, and problem solutions. The last-mentioned problem is a routine mathematical problem that does not test students' creativity. In addition, teachers also feel that their knowledge is insufficient to construct creative problem-solving-based assignments in mathematics (Haavold & Birkeland, 2017).

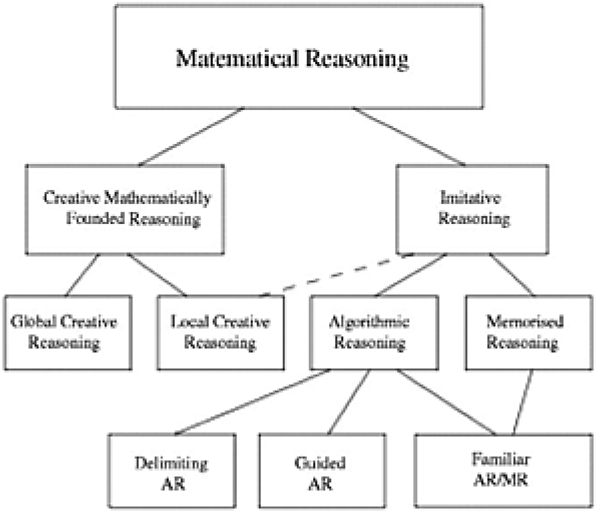
Based on this description, increasing the ability of mathematical creativity or creative reasoning (CR) is an important ability for students to compete in the 21st century and at least solve their problems using good reasoning. The previously described information states that several problems at school contribute to students' loss of creativity or CR after graduation, resulting in students' inability to deal with real situations, especially in solving uncertain (non-routine) problems. However, it is necessary to analyse the core issues related to the quality of students' CR in schools so that the development of their abilities can run well. The leading indicator of students' mathematical creativity is mathematical reasoning ability because reasoning ability is related to basic abilities or students' mathematical potential to support higher mathematical ones; besides, most Indonesian students' reasoning abilities are still relatively low based on several studies seen from the PISA score (Program for International Student Assessment) for Indonesian students (Herman, 2021; Ninawati et al., 2022). Therefore, this article discusses the analysis of the quality of students' reasoning abilities in one of the junior high schools (SMP) in Cianjur Regency, Indonesia, to describe the actual problem of the low mathematical reasoning abilities of Indonesian students and relate them to the teacher's perspective on the learning process.

METHODOLOGY

This study uses a qualitative approach using a framework Lithner (2008) related to creative and imitative reasoning. The following is an overview of Lithner's mathematical reasoning framework.

Figure 1

Overview of Lithner's mathematical reasoning framework



The framework shows that imitative reasoning consists of two categories of reasoning quality: reasoning algorithm (AR) and memorial reasoning (MR). In addition, creative reasoning (CR) consists of global creative reasoning and local creative reasoning, but in this article, global and local creative reasoning are considered as one category, namely CR.

Based on this framework, the quality of AR is indicated by the following conditions (Lithner, 2008):

1. The choice of strategy is to remember the solution algorithm. The predictive arguments may differ but do not create a new solution algorithm.
2. The reasoning used after implementing the strategy is of low quality; the way to avoid wrong answers is not to make careless mistakes in implementing the algorithm.

The quality of MR is indicated by the following two conditions (Lithner, 2008):

1. The choice of strategy is by memorising the correct answers.

2. Implementation of the strategy is only writing down the answers that are memorised.

Furthermore, the quality of CR is indicated by the following conditions (Lithner, 2008):

1. Novelty. Reasoners carry out reasoning sequences or, in other words, complete existing strategies.
2. It makes sense. There are arguments in favor of strategy choice and/or strategy implementation that motivate why the conclusion is correct or plausible.
3. Mathematical foundation. The arguments given are based on mathematical rules.

Based on Lithner's perspective, a criterion for assessing the quality of mathematical reasoning was compiled to facilitate the analysis in this study (Herman, 2018).

Table 1

Criteria for grouping mathematical reasoning

Code	Explanation
NA	Answer wrong/blank/not suitable.
MR	Explain the answers without giving a supportive reason, mentioning and defining supporting terms against the answers given.
AR	Outlining the answer in detail and giving reasons for the answers given
CR	The answer contains components of fluency, flexibility, originality, and elaboration.

In these criteria, there is an NA code, a category when students do not answer correctly, do not answer at all, or do not reach the expected answer. The sample used in this research is the quality of reasoning ability of junior high school students in Cianjur Regency obtained from the test results of 27 students through four tests of students' mathematical reasoning ability.

Qualitative descriptions in this paper are also carried out through literature studies based on the results of interviews conducted with mathematics teachers related to the process of learning mathematics. The results of the literature study describe suggestions for solutions that the teacher or subsequent researchers can carry out to improve students' mathematical reasoning abilities so that they can foster students' mathematical creativity abilities.

Ethics Statement

This research has obtained approval from the research subjects, both teachers and students, who have signed the informed consent form (ICF). The implementation of this research has also received approval from the school principal, where the research subjects are located, through an official letter from the academic vice-rector of the researcher's campus. Therefore, the research team did not request a previous ethical assessment by the appropriate councils of the research project. Thus, through this statement, we exempt Acta Scientiae from any consequences arising, including full assistance and possible compensation for any damage to any research participants, as per Resolution N. 510, dated April 7, 2016, of the National Health Council of Brazil.

RESULTS AND ANALYSIS

Based on the four reasoning questions completed by students, Table 2 categorises students' reasoning abilities into four categories (NA, MR, AR, and CR).

Table 2

Data on quality of reasoning mathematics

Question	Quality of Reasoning			
	NA	MR	AR	CR
1	21 (78%)	5 (19%)	0 (0%)	1 (1%)
2	26 (96%)	1 (4%)	0 (0%)	0 (0%)
3	21 (78%)	4 (15%)	2 (7%)	0 (0%)
4	23 (85%)	4 (15%)	0 (0%)	0 (0%)

Table 2 indicates that most students' reasoning abilities fall under the NA category. This means that almost all students do not demonstrate mathematical reasoning abilities. Based on the student's response outcomes, most students answered incorrectly in almost every reasoning question and did not provide any reasoning arguments. Only one student showed CR (creative reasoning), but only in question number one. Table 2 shows that the student's response arguments fall into the categories of memorisation and algorithm, indicating that the student's overall mathematical reasoning abilities are generally at the imitative level.

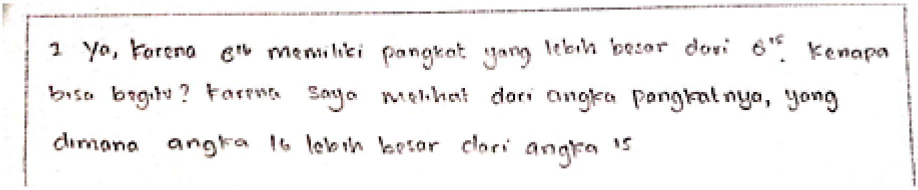
The results illustrate an issue with the mathematical reasoning abilities of junior high school students in Cianjur, Indonesia. To identify the main problem behind the low reasoning abilities of students, the following is an analysis of student responses along with the provided reasoning arguments based on the number of questions and categories of mathematical reasoning quality.

Question number 1 (S1)

Table 2 indicates that 26 students, or 78% answered incorrectly or did not attempt the questions at all. Five students (19%) answered correctly with MR quality arguments, and one (4%) answered correctly with CR quality. Figure 2 shows one of the student's works with MR quality.

Figure 2

Example of MR quality student work for S1



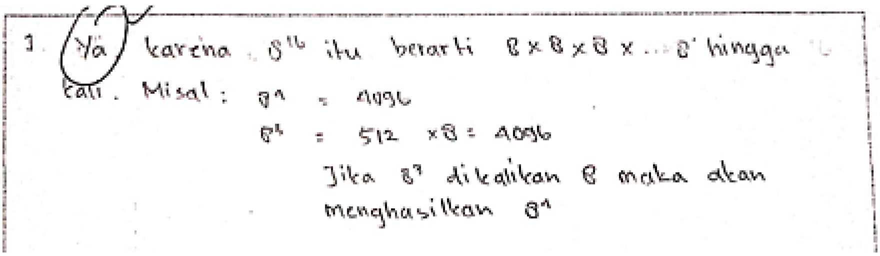
Translation: *1 Yes, because* 8^{16} *has higher power than* 8^{15}. *How come? Because I see from the exponential number, which is where the number 16 is greater than the number 15.*

The student's work in Figure 2 shows that the student is trying to recall the concept of exponential numbers and understand the example given at the beginning of the test to connect it with question S1. However, the student quickly concludes the answer without providing any other arguments to ensure that 8^{16} is indeed eight times larger than 8^{15}.

Furthermore, Figure 3 shows the only student who demonstrates the quality of CR ability.

Figure 3

Example of CR quality student work for S1



Translation: *1. Yes, because* 8^{16} *means* $8 \times 8 \times 8 \times \ldots \times 8$ *to* 16 *times. For example:* $8^4 = 4096$, $8^3 = 512\ x\ 8 = 4096$. *If* 8^3 *is multiplied by* 8 *it will produce* 8^4.

Figure 1 depicts the student’s understanding of the calculation process using exponential numbers. However, the large numbers in the question make it challenging to perform manual operations. The student takes the initiative to use a smaller exponential form to estimate the answer to S1. Then, based on this example, the student concludes that 8^{16} is eight times larger than 8^{15}.

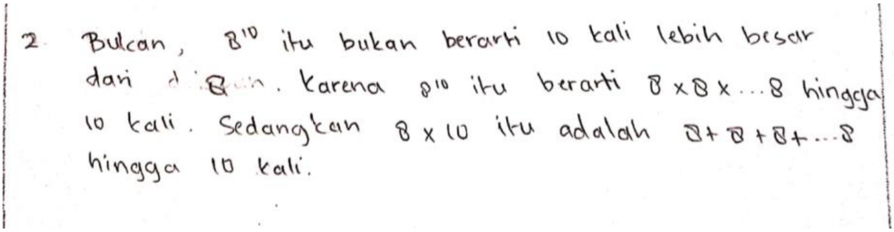
Even though the student does not provide epistemic arguments, how the student builds conjectures from smaller examples is the first step in building knowledge through an inductive method of answering S1 statements.

Question number 2 (S2)

In question number 2, only one student answered correctly with MR quality, while the remaining 26, or 96% answered incorrectly or did not attempt the question. Figure 4 displays the work of a student with MR quality.

Figure 4

Example of MR quality student work for S2


2. Bukan, 8^{10} itu bukan berarti 10 kali lebih besar dari 8. Karena 8^{10} itu berarti $8 \times 8 \times \ldots 8$ hingga 10 kali. Sedangkan 8×10 itu adalah $8 + 8 + 8 + \ldots 8$ hingga 10 kali.

Translation: *2. No,* 8^{10} *is not* 10 *times as big as* 8. *Because* 8^{10} *is 8* $8 \times 8 \times \ldots 8$ *to* 10 *times. Whereas* 8×10 *is* $8 + 8 + 8 + \ldots 8$ *to* 10 *times*

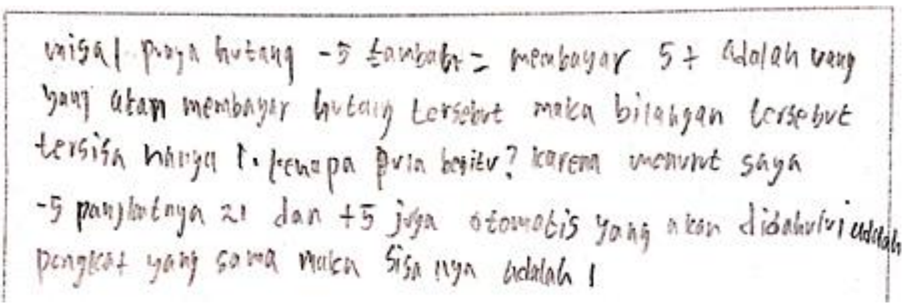
Students answer questions by connecting their understanding of exponential numbers with how to solve S2. Students try to explain that there is a different concept between 8^{10} and 10 multiplied by 8.

Question number 3 (S3)

Figure 5 is one of the worksheets of students who answered S3 correctly with MR quality.

Figure 5

Example of MR quality atudent work for S3


misal punya hutang -5 tambah = membayar 5 + adalah uang yang akan membayar hutang tersebut maka bilangan tersebut tersisa hanya 1. kenapa bisa begitu? karena menurut saya -5 pangkatnya 21 dan +5 juga otomatis yang akan didahului adalah pangkat yang sama maka sisanya adalah 1

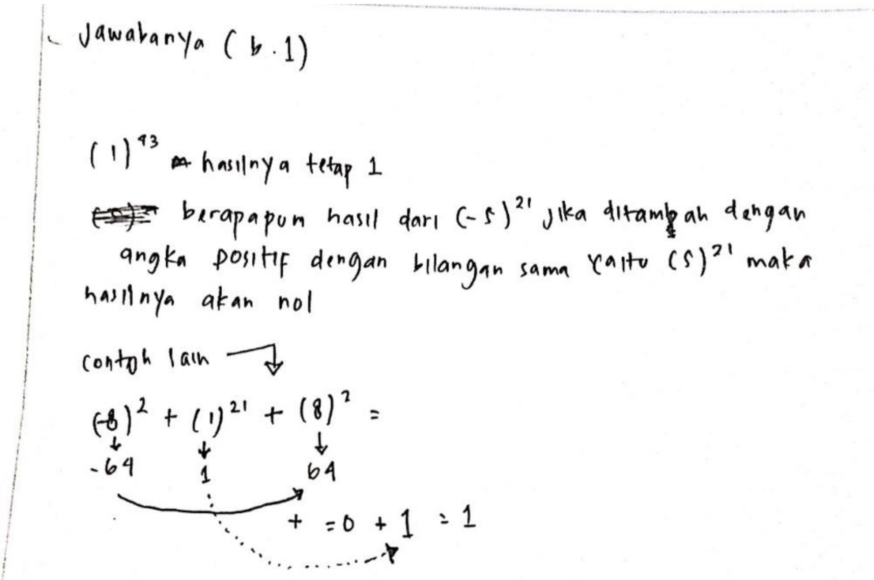
Translation: *For example, if you have a debt of -5 plus = pay +5 is the money that will pay off the debt, then there is only 1 left. Why is that? Because, in my opinion, -5 has a* *power of 21 and +5 too, automatically, what will be preceded is the same power, so the remainder is 1.*

The student, shown in Figure 5, began his work by investigating the same base power numbers, namely -5 and 5. Starting from there, the student realised that the numbers had the same power, namely 21. The student concluded that they only needed to operate on -5 numbers and 5 because they assumed the rank results would be the same. After that, the student could easily conclude that the outcome of the problem is one, based on 1^{43}.

Students who answered S3 with AR quality are shown in Figure 6.

Figure 6

Example of AR quality student work for S3



Translation: *The answer (b.1)*

$(1)^{43}$ *the result is still 1. Whatever the result of* $(-5)^{21}$, *if it is added to a positive number with the same number, namely* $(5)^{21}$, *the result will be zero.*

Another example: $(-8)^{21} + (1)^{21} + (8)^{21} = -64 + 1 + 64 = 0 + 1 = 1$

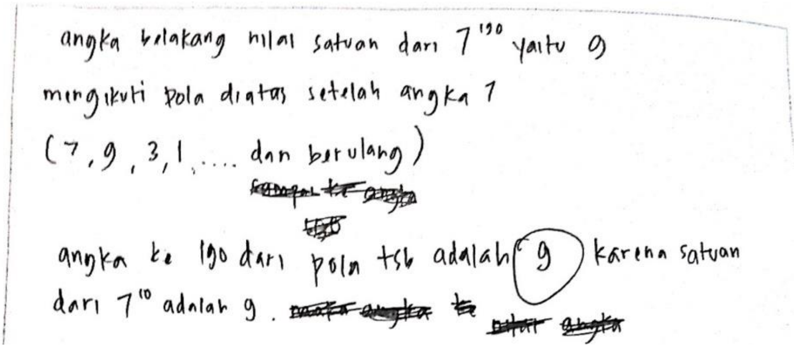
The student provides a different solution from the previous student (regarding the quality of the MR). The student argues about the odd-even result as an exponent with an odd base number. Furthermore, to convince their arguments, the student provides examples with low-power numbers, namely $(-8)^2$ and 8^2.

Question number 4 (S4)

There were only four students who did question number 4 correctly and all of them were with MR quality. One of the answers provided by the four students is shown in Figure 7.

Figure 7

Example of MR quality student work for S4



Translation: *The last digit of the unit value of* 7^{190} *is* 9*, following the pattern above after the number* 7 *(7,9,3,1, ... and repeating); the 190th number of the pattern is 9 because the unit of* 7^{10} *is 9.*

The student answered question number 4 by first analysing the pattern of the unit digit in powers with a base of 7. The student has identified a repeating pattern of 7, 9, 3, 1. Although some of the student's explanations are missing, they were able to correctly conclude the answer. They stated that the units digit 7^{190} and 7^{10} is the same, which is 9.

Problem Analysis

The findings related to the low reasoning abilities of junior high school students in Cianjur, Indonesia, indicate that there are actual problems that need to be resolved before implementing learning strategies, methods, or models for developing students' mathematical creative abilities. Based on the four questions given to test students' reasoning abilities, 78% of students did not answer question number 1 correctly, 96% did not answer question number 2 correctly, 78% answered wrong question number 3, and 85% answered wrong question number 4. The results show that the problem of the reasoning ability of students in one of the junior high schools in Cianjur, Indonesia, is at a very basic level, meaning that most students do not understand the solution at all to solve the given reasoning questions. In addition, on average, in 20% of students who answered correctly the questions given, the student reasoning abilities were only at the level of imitative reasoning, with indicators of memorial reasoning (MR) and reasoning algorithms (AR). Only 1% of students had creative reasoning abilities (CR); the rest of the student's answers showed MR and AR abilities.

Students' Basic Mathematical Ability

The results of the interview with the mathematics teacher at the school provide a more detailed depiction of the current issues related to students' low reasoning abilities. First, the researcher posed a question regarding the teacher's opinion on the difficulties students face in understanding mathematical concepts in the classroom, as shown in the following transcript:

Researcher : *"According to you, what are the difficulties in teaching mathematics in class?"*

Teacher : *"Some students have not mastered the basic skills at elementary school such as (multiplication, division, and addition) because when they were in grades 5 and 6, they were in the COVID period where learning did not go as it should. So that when applying to new material, some students are still confused."*

The teacher answered that the difficulty of teaching mathematics in class was due to elementary school students' lack of basic math skills. He also provided details of the basic skills, namely the ability to operate numbers (addition, subtraction, multiplication, and division). Even though the teacher gave the opinion students' difficulties were caused by the implementation of online learning due to COVID-19, this is still debatable, so the point of this answer is that the main problem is students' low basic math skills. This statement is reinforced through other questions in the same interview below:

Researcher	:	*"In your opinion, what causes students to have difficulty learning mathematics?"*
Teacher	:	*"The basic concept of counting is not understood, and consider mathematics difficult before trying it."*

The second answer validates that the main problem with students' difficulty in understanding mathematical concepts is that students do not understand the basic concepts of calculation. In addition, the teacher also assumes that students already have the notion that mathematics is a complex subject.

The teacher's answer is related to the students' low basic math ability by the results of students' answers on the reasoning ability test. Most students could not use their reasoning in determining the comparison of multiple problems shown in exponential numbers in questions 1 and 2. This inability identified that the student's main problem was not in understanding the concept of exponents, but in understanding the concept of multiplication operation; inn this case, the aspect being tested was multiples number.

Determination of Learning Strategies and Media

The following interview question relates to the teacher's learning strategy to improve students' understanding of mathematics. The following is a transcript of the interview regarding the learning strategy:

Researcher	:	*"How do you usually teach math in class?"*
Teacher	:	*"Usually, I teach math students in class by relating it to everyday life, various solutions and proofs so that students are motivated to choose which method and prove that the answer is correct because it will be applied in everyday life in the future."*

The teacher's answer shows that the teacher has used a learning strategy that connects mathematics material with everyday life. The teacher also provides open problem questions, with the aim that students can be motivated and can be applied by students in real life. This means that teachers have used various strategies in teaching mathematics. However, the problem is that the strategies used by teachers have not been able to develop students' reasoning skills, as indicated by the low results of students' reasoning tests. This is also related to the low ability of students in basic mathematics.

Then, teachers were asked questions about the learning media used in the classroom. The following is the interview transcript:

Researcher : *"What teaching materials are used in teaching mathematics in class? Like a textbook or something."*

Teacher : *"The teaching materials that I use are books from the Ministry of Education and Culture of the Independent Curriculum."*

The interview answers illustrate that the learning process was carried out with a contextual approach and open-ended problems, which illustrates that students have been given learning opportunities to improve their mathematical abilities.

Student Learning Independence

The following is an interview transcript with the teacher regarding the student's learning independence:

Researcher : *"In your opinion, do students enjoy learning mathematics on their own even if there are assignments or not?"*

Teacher : *"Students seem to only learn when given assignments, especially for math lessons; maybe only a few students repeat material at home or study independently without being given assignments first."*

The interview results show that students have low motivation to learn mathematics; this also affects students' enthusiasm to explore the material independently. Students only learn when given assignments by the teacher.

Solution Recommendation

The author identifies several solutions to the problem of low mathematical reasoning quality based on students' reasoning test results, teachers' perceptions of the learning process, and teachers' assessment of students' abilities. The problems identified by the author based on this are divided into several sections, including student ability, student affect, and various mathematical challenges. These problems were identified according to the (Leikin, 2009) framework related to the learning environment that supports students in developing their mathematical potential.

Analysis of Students' Mathematical Potential

The relationship between students' low cognitive abilities and the results of interviews with teachers who stated that learning had been carried out through contextual approaches and open problem models showed that there was no diagnostic test at the beginning of learning conducted by the teacher. This means that teachers do not understand the mathematical potential of students; as a result, the learning strategies and methods used have not provided optimal results. Therefore, there must be a clear relationship between mathematical potential and the mathematical challenges the teacher gives.

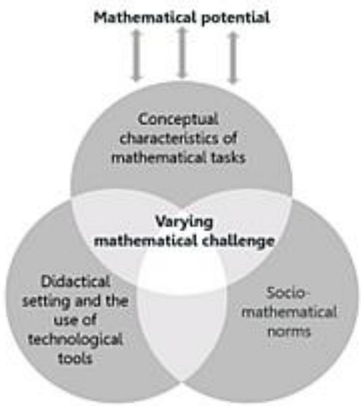
The relationship between mathematical potential and the mathematical challenge is shown in Figure 8 (Leikin, 2009).

The definition of a mathematical challenge is a difficulty that can be approached with potential mathematical abilities such as ability, influence or motivation, personality, and previous experience when someone solves a difficulty. The arrow from challenge to mathematical potential in Figure 8 indicates the relative nature of the mathematical challenge and suggests that teachers should understand students' characteristics (Leikin, 2009). Furthermore, the variety of mathematical challenges is a notable component of the learning opportunities that students should receive to realise their' mathematical potential. Such variety should aim to cultivate students' abilities and generate student motivation through an enjoyable process (Leikin, 2009).

Figure 8 shows three main factors of various mathematical challenges, which means that the selection of tasks or problems given to students depends on these factors or a combination of them. The first factor is determining the mathematical challenge associated with the conceptual characteristics and structure of the mathematical task. These characteristics are conceptual density with indicators of the number of concepts and properties needed to solve problems, such as logical relationships and the length of task solutions. The second and third factors are socio-mathematical norms and the use of technology. From a didactical perspective, collaborative learning, where students can ask each other questions and help each other share ideas, can increase the challenge. Furthermore, the use of technology, namely dynamic mathematics software, can create opportunities for students to work with investigative tasks that lead to deeper inquiry, making it more challenging for students. Technology also reduces cognitive load by providing visual displays to aid the thinking process and increasing the math challenge.

Figure 8

Relationship between mathematical potential and mathematical challenges



Finally, the learning process aims to explore the potential of each student, so there is no loss of talent due to the learning process that pays little attention to individual potential (Leikin, 2009; Milgram & Hong, 2009). Efforts to individualise learning that previously seemed so impossible are now possible using technology (Milgram & Hong, 2009). Technology-integrated learning environments can be used to differentiate curricula and individual teaching in regular classes for all individuals with their potential (Leikin, 2009; Milgram & Hong, 2009). As a result, the process of creativity will be formed with this integrated learning environment.

Varying Mathematical Challenges

Previously, we explained that to foster students' mathematical potential, mathematical challenges are needed, which can be done through teacher intervention. This relates to the strategies, methods, or learning models teachers apply to foster students' mathematical potential to develop mathematical creativity (CR) abilities. The teacher's learning design must be adjusted to the student's learning conditions to encourage students' reasoning and conceptual thinking skills (Firmasari et al., 2022).

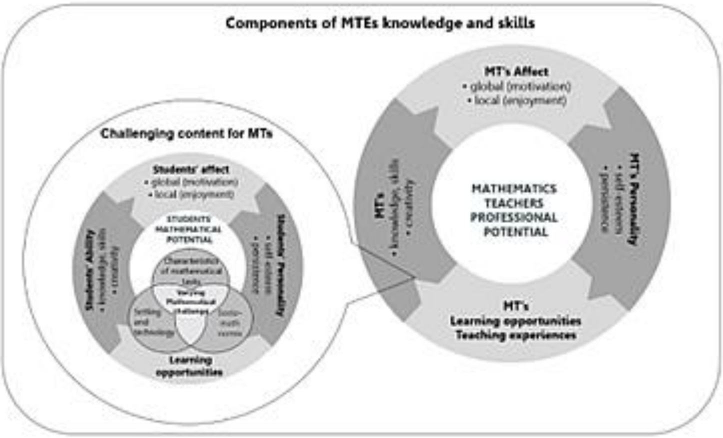
In addition, innovations made by teachers to reduce students' cognitive load so that it is easier to understand mathematical concepts are effective ways that teachers can use to foster students' mathematical reasoning and creative thinking skills (Febriandi et al., 2022). However, the main problem is that teachers must have qualified competencies to implement mathematical challenges in the classroom. Siswono et al. (2017; 2018) analysed the influence and teacher responses to problem-based learning on improving creative thinking skills in mathematics. Based on the research conducted, they found that teachers must have the ability to understand the implementation of problem-solving in teaching practice. Furthermore, teachers' ability to understand the meaning and strategies of problem-solving is still not enough to direct students to think creatively. However, based on Siswono et al. (2018), the majority of Indonesian teachers' mathematical literacy is still relatively low; this is indicated by errors in selecting relevant information, low creative thinking skills in the tasks given to students, and low understanding of mathematical concepts, shown in the assignment questions given.

The first recommendation relates to mathematical challenges. Some researchers recommend problem-posing-through-investigation (PPI) as a learning approach to develop CR skills. PPI is usually used together with multiple solution tasks (MST) (Hafizi & Kamarudin, 2020; Leikin & Elgrably, 2020, 2022). In addition, there are approaches based on how students process problem solutions, one of which is the numerical pattern and diagram (picture) problem-based approach. This approach relies on students' convergent thinking, while divergent thinking serves as a complement to convergent thinking on multiple-solution tasks. This approach also refers to generalising a problem and is the first step in mathematical proof (de Vink et al., 2022; Eraky et al., 2022).

The second recommendation is an alternative solution related to teachers' low competence to provide questions to develop students' CR skills. To overcome this obstacle, there is a good theory by Leikin (2021), as well as several studies that are relevant to this theory. Leikin mentions in his research that a hierarchical relationship exists between teacher potential, challenge content from teachers, and student potential. Figure 9 illustrates the hierarchical structure.

Figure 9

Hierarchical structure of professional potential teachers on students' mathematical potential



This structure provides a foundation regarding the barriers to teachers' competence, the learning process that supports students' potential, and challenging tasks that align with students' abilities. This structure also aligns with the research conducted by Haavold and Birkeland (2017), which states that teachers need an environment or system that can accommodate the aforementioned constraints.

Student Learning Style

The problem of students' learning independence leads to low motivation and cognitive abilities. Based on the Leikin framework in Figure 2, this issue, apart from external factors, can also arise from internal factors, namely, students' personalities, which means that teachers must identify students' characteristics and backgrounds. The students in the 2022 school year belong to Generation Z, which includes individuals born between 1995 and 2012. Currently, this generation is between 10 and 27 years old. Generation Z is associated with various terms such as Generation N (Net), Generation D (Digital), Generation V (Viral), Google Generation, Sharing Generation, "all technology all the time", "born digital", digital natives, Generation 2020, iGen, Gentech, and Gen Wii (Azman, 2021; Engelbrecht et al., 2020; Szymkowiak et al., 2021). All of these terms refer to the behavioural patterns of Generation Z, which are closely related to technology and the internet. Based on their characteristics, Generation Z exhibits traits such as a greater interest in technology-based media over traditional media, continuous use of gadgets and the internet, interest in various subjects and issues, a global mindset and communication style, low attention span, and a tendency to multitask (Azman, 2021; Hernandez-de-Menendez et al., 2020; Szabó et al., 2021; Szymkowiak et al., 2021).

Research shows that the brains of Generation Z are structurally different from previous generations due to the high intensity of gadgets and internet usage. The brains of Generation Z have a more developed visual processing aspect compared to other parts, which enables them to process visual information efficiently (Szabó et al., 2021; Szymkowiak et al., 2021). Polakova and Klimova (Szymkowiak et al., 2021) also emphasise that Generation Z's attention span is shorter than previous generations. According to Polakova and Klimova, the attention span of Generation Z ranges from 7 to 10 minutes, which means that Generation Z can only concentrate on reading for less than 20% of a given period and has lower tolerance without digital resources. Generation Z heavily relies on technology and the internet as they use them to seek information in various aspects of their lives, including learning. Therefore, Generation Z prefers learning on the Internet rather than using paper-based materials.

To be able to acquire knowledge, information needs to be explored in depth and stored in long-term memory. Meanwhile, Gen Z's attentional ability is relatively low. However, they can quickly obtain information from various information digitally, resulting in this information being stored only in short-term memory (Szabó et al., 2021).

Student self-confidence, belief, and student involvement in the learning process are the keys to the success of the independent learning process. Coaching of the learning process carried out by the teacher determines the level of success of the learning process. The role of the teacher will affect the learning process that will occur. However, the teacher must consider many variables so that the learning process can run effectively and achieve the expected learning objectives. Learning styles, student characteristics, and optimising the independent learning process are vital indicators that teachers need to include when fostering the learning process (Bishara, 2021; Cardino Jr & Cruz, 2020; Tay et al., 2021; You et al., 2021).

As previously discussed, the learning environment is a strategy teachers must employ to optimise the process of independent learning for students. Independent learning is part of developing students' potential and teachers' competence, aiming to foster mathematical creativity. Several studies indicate that focusing on the development and improvement of teachers' competencies will cultivate teachers' awareness in developing an effective learning environment that considers students' needs, skills, prior mathematical experiences, and learning style preferences, enabling students to solve mathematical problems (Bishara, 2021; Mann & Willans, 2020; Son & Fatimah, 2020; You et al., 2021). Similarly, as discussed earlier regarding mathematical creativity and potential, an integrated learning environment is currently considered one of the best ways to develop an effective learning process that benefits students' future success. This means that the learning environment accommodates students' characteristics, such as learning styles, personalities, learning histories, self-directed learning abilities, and using technology to aid the learning process. Furthermore, the learning environment assists teachers in developing their competencies by implementing the structure designed by Leikin (2021). In general, individualising the learning process and implementing different curricula within a learning process are essential aspects to be implemented currently, considering that students' abilities and potential in learning are diverse and unique.

Use of Technology

The internalisation of learning and curriculum processes is nearly impossible without the assistance of technology, given the cognitive load and limitations of the teacher's role. The use of technology is also encouraged for high school students. Research findings show that using technology in the learning process does not lead to addiction. However, the role of the teacher in establishing rules and guidelines for the use of technology is crucial, as students tend not to store the vast amount of information they acquire through technology in their long-term memory (Han, 2022; Richards et al., 2021; Salnikova et al., 2020).

Several studies also show that the use of technology is quite effectively applied in the learning process, both in the form of instructional learning systems, learning videos, and digital learning modules (Ismail et al., 2021; Jarvis et al., 2021; Novita & Herman, 2021; Tay et al., 2021). However, in developing a technology-based learning process, it is necessary to consider several things, including 1) there is no software application for all learning processes; 2) teachers must pay attention to student involvement in the learning process; 3) the development of teacher professionalism in technological literacy must be considered; 4) there needs to be teacher-student interaction outside of the digital platform; 5) teachers must be able to develop students' independent learning processes.

Several studies state that technology plays a vital role in mathematics learning and the practice of mathematical literacy. However, the instruments used in integrating technology in developing mathematical literacy must consider the pedagogical aspects and the concept of mathematics itself. Using digital technology does not mean the teacher's presence in learning is no longer needed. Instead, its role changes to that of designer and facilitator who will ensure the creation of learning that can adequately cover mathematical literacy and digital literacy.

CONCLUSION

This study demonstrated the shallow reasoning ability of students from one of the junior high schools in Cianjur, Indonesia, demonstrated by the number of students who could not answer the reasoning test. In addition, students who could answer the questions (less than 20%) showed the quality of imitative reasoning skills, meaning that students only relied on memorial reasoning (MR) and reasoning algorithms (AR) to answer the questions. The test results also showed that only one student answered with the quality of creative reasoning (CR). The results of interviews with mathematics teachers also showed that the main problem was the low quality of students' mathematical reasoning as a result of students' low basic mathematics skills, especially in mathematical calculations (addition, subtraction, multiplication, and division). Furthermore, the absence of a connection between students' abilities and mathematical challenges makes it difficult to develop reasoning skills and foster students' mathematical creativity (CR). The author's analysis shows three main problems with students' low reasoning ability: low cognitive ability, mathematical challenges matching students' abilities, and student affection. Therefore, based on the literature review, several suggestions can be made in future research to resolve these problems measurably. The study suggests that teachers must analyse students' mathematical potential, connect students' mathematical abilities with potential-based challenges, consider the learning styles of Generation Z students, and use appropriate technology to implement mathematical challenges.

AUTHORS' CONTRIBUTIONS STATEMENTS

SM carried out conceptualisation, developing theory, writing the original draft, editing, and visualisation; TH was responsible for reviewing, editing, and developing theory; DD was responsible for the review, formal analysis, and methodology; NDP worked on editing and proofreading the article.

DATA AVAILABILITY STATEMENT

Anyone making a reasonable request to the first author of the article, SM, will be provided with the supporting data for the research findings.

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