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The Importance of Understanding Exponent Number Concept in Science Scope: Students' Abstraction Thinking Level in Problem Solving

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Abstract: Mathematics is closely related to science because both require the ability to analyze, think logically, and systematically to understand. This study explores students' level of abstraction thinking in understanding the concept of exponent numbers and its implementation in science. This research uses a qualitative approach. The subjects in this study were students of the master's program in basic education. The data collection techniques used were tests and interviews. The results showed differences in identifying exponent numbers in low and high abstraction level students. Low abstraction level students perform problem-solving stages, such as identifying and writing down every information listed in the problem, using mathematical symbolization, performing number operations according to problem understanding, and checking again. Meanwhile, high abstraction level students performed problem-solving stages, such as identifying every piece of information in the problem without writing it on the worksheet, not writing the results of their understanding explicitly on the worksheet, not writing explicitly the model to be used, performing number operations without paying attention to the type of number because they already understood and they made a conclusion. Both level students applied the concept of exponent numbers in science for writing units and density.

Keywords: Abstraction thinking; Exponent numbers; Problem solving; Science

Introduction

Mathematics is an essential branch of science because it is closely related to other scientific disciplines, especially science. In science, it is inseparable from metamatic calculations because many physics statements need to be expressed in mathematical language (Risdianita, 2024). In addition, the field of science also discusses fundamental problems that require analysis, logical thinking, and systematic thinking. However, this has yet to be supported by the mathematical thinking skills of prospective teacher students when studying mathematics and science.

Research shows that many students still need help understanding mathematical concepts when learning science, especially physics (Kereh et al., 2013; Risdianita, 2024). Because of these student difficulties, it is necessary to prepare prospective teachers for students who can understand mathematical concepts in the field of science to avoid raising misconceptions in students. Furthermore, research on the level of abstraction

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thinking in understanding or solving mathematical problems is often done on students, so not many have been done on prospective student teachers (Abiodun et al., 2024; Hong & Kim, 2016). On the other hand, the level of abstraction thinking in understanding the concept of power numbers or exponents is essential because it is a provision for studying other fields of science, such as science (Akcanca, 2020; Nakakoji & Wilson, 2020).

The Exponent of numbers is a fundamental concept of mathematics that has a crucial role in various fields of science, especially science. This concept allows us to represent very large or very small quantities in science more efficiently. However, an in-depth understanding of power numbers not only requires students to master mathematical operations but also to be able to think abstractly to identify this concept in various scientific phenomena (Astuti & Misbahudholam, 2023; Krenn et al., 2022; Pacheco & Herrera, 2021). This research aims to identify pre-service teachers' abstraction thinking level in identifying the concept of exponent numbers and their implementation in science.

Abstraction is a crucial process in acquiring knowledge and resolving mathematical problems (Ferrari, 2003). Abstraction is the process, technique, and outcome of distilling fundamental notions to comprehend and address issues (Rich & Yadav, 2020). An abstraction method can serve as a foundational concept for resolving mathematical issues. The concept may pertain to a definition or theorem relevant to the mathematical situation (Sa'adah et al., 2023). Abstraction is the process of isolating genetic information from several specific objects or circumstances (Savaş & Yavuzsoy Köse, 2023). The abstraction activity can assess the quality of the interaction between the thinker and the object of contemplation.

Thinking is a cerebral process that facilitates knowledge retention, comprehension, exploration, analysis, or synthesis of mathematical problems (Faizah & Sudirman, 2022). Abstraction in mathematical cognition facilitates the assessment of pupils' problem-solving capabilities (Faizah et al., 2022). Student activities' abstractions occur when mathematical concepts are treated as independent objects, establishing linkages through defined processes and methods (Savaş & Yavuzsoy Köse, 2023). Two levels of abstraction exist: high and low (Rich & Yadav, 2020), as illustrated in Figure 1.

Figure 1 demonstrates that the high level of abstraction can be categorized as contextualized word problems, which encompass comprehensive information regarding the context of the problem, yet require a more explicit presentation of the less detailed problem-solving process. The low level of abstraction is referred to as decontextualized arithmetics, which offers specific instructions on the actions to take and is presented in a clear manner (Rich & Yadav, 2020). The level of pupils' abstract thinking in comprehending the notion of exponentiation can be assessed through their problem-solving in mathematics. In this instance, employing Polya's four steps of problem-solving.

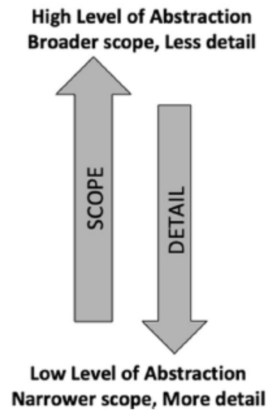

Figure 1. Level of Abstraction

Initially, understanding the problem entails analyzing all information within the mathematical query, identifying unknown variables, and delineating the problem's conditions. Secondly, devising a plan, namely identifying a solution strategy, structuring data, and attempting to resolve the issue incrementally. Third, carry out the plan; at this juncture, it is essential to validate each phase of the solution, perform all computations, and execute all strategies established during the planning stage. The final phase is to looking back, assessing its correctness, reviewing the logic, exploring alternative methods for problem-solving, and determining the applicability of the approach (Rocha & Babo, 2024).

Therefore, this study aims to explore prospective teacher students' abstraction thinking level in understanding the concept of power numbers and to identify their ability to apply it to science. The existence of this research is expected to prevent prospective teacher students from having difficulties in providing understanding to students about the relationship between the concept of power numbers or exponent numbers and the field of science.

Method

This study uses a qualitative exploratory research approach. The study's subjects were students enrolled in the master of basic education program who focused on multidisciplinary courses. Research subjects are chosen according to high and low levels of abstraction. Written test instruments and interviews were used to gather data for this investigation. The written test was related to understanding the basic concepts of exponents or power numbers. The written test was used to identify prospective teachers' understanding of the basic concepts of exponent numbers so that they would not have difficulties implementing them into the field of science. The written tests used in this study are "Let $p, q, n \in W$ and $n \geq 1$. Determine if $(a+b)^n = a^n + b^n$ is always true, sometimes true, or never true. Justify your conclusion!"

When students have completed the test, they are then classified based on the level of abstraction thinking. After that, the research subjects were interviewed semi-structured based on the written test results. The interview with the subject was conducted in-depth to reveal the subject's understanding of the concept of exponent numbers and its implementation in the field of science.

This study employed qualitative data analysis, encompassing data reduction, interpretation, and conclusion formulation. Data reduction is performed to select data aligned with the research objectives, whereas data not aligned with these objectives is regarded as findings. Data interpretation involves elucidating the reduced data. The final step involves drawing conclusions derived from the results of data interpretation. This study's data analysis utilized the abstraction thinking framework established by Rich et al. (2020) and the mathematical problem-solving stages proposed by Polya.

Result and Discussion

Based on the study's results, it was found that four students fell into the category of *high-level abstraction*, and six students fell into the category *of low-level abstraction*. Four students were randomly selected from each level to be interviewed in depth. In this case, the subject with the *low level of abstraction* category is referred to as SL and the subject with the *high level of abstraction* category is referred to as SH. The results of the investigation of each category of subjects are as follows.

Subjects with the SL category completed the test in detail, as in Figure 2. Students in the *low-level abstraction* category performed the stage of understanding the problem by identifying each piece of information contained in the problem and then writing it explicitly on their worksheets. Students write the results of understanding the problem by writing the meaning of mathematical symbols contained in the problem.

Then, when making a plan, SL students use memorization by taking any integer to test the truth of the claims in the problem. Then, proceed to the plan implementation stage; at this stage, SL students memorize using symbols and then substitute into the form $(p+q)^n = p^n + q^n$. From the substitution and operation results, it was concluded that the statement in the problem is not always true; in this case, it depends on the rank. If the rank is $(n = 1)$, then the statement in the problem is always true, but if the rank is $(n > 1)$, it is always false.

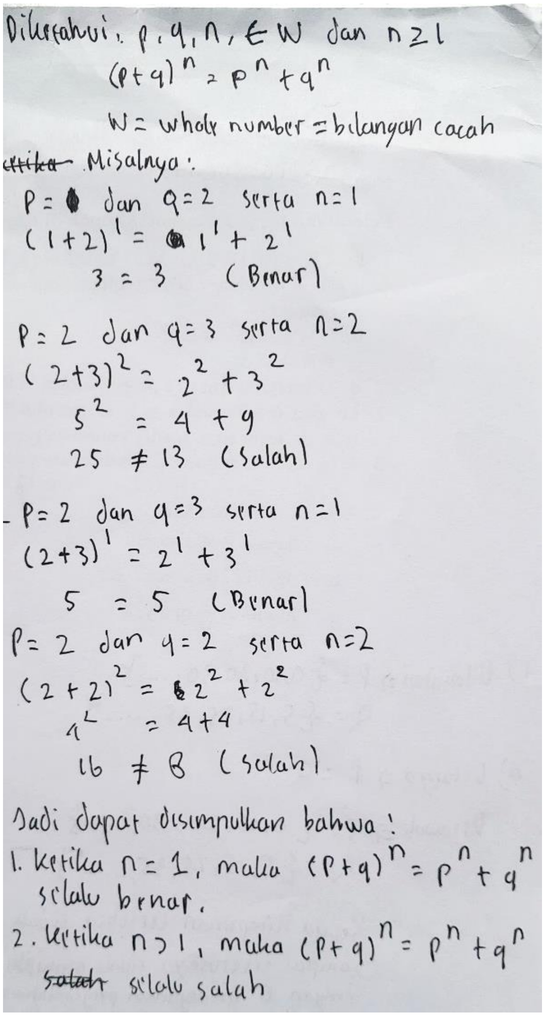
Diketahui: p, q, n, ∈ W dan n ≥ 1
$(p+q)^n = p^n + q^n$
W = whole number = bilangan cacah
Misalnya:
p = 1 dan q = 2 serta n = 1
$(1+2)^1 = 1^1 + 2^1$
3 = 3 (Benar)
p = 2 dan q = 3 serta n = 2
$(2+3)^2 = 2^2 + 3^2$
$5^2 = 4 + 9$
25 ≠ 13 (Salah)
p = 2 dan q = 3 serta n = 1
$(2+3)^1 = 2^1 + 3^1$
5 = 5 (Benar)
p = 2 dan q = 2 serta n = 2
$(2+2)^2 = 2^2 + 2^2$
$4^2 = 4 + 4$
16 ≠ 8 (Salah)
Jadi dapat disimpulkan bahwa:
1. ketika n = 1, maka $(p+q)^n = p^n + q^n$ selalu benar.
2. ketika n > 1, maka $(p+q)^n = p^n + q^n$ selalu salah

Figure 2. Result of SL Work

R : *Do you know what the question means?*
SL : *I know, Mom. In this problem, there is a statement, and then I am asked to prove the truth of the statement.*
R : *How do you prove it?*
SL : *When I understood the question's meaning, I memorised n≥1, so let us say n=1 and n>1. In the problem, p, q, and n are integers, so I used any integer as a model to prove the truth of the claim. I then substituted it into the form* $(p+q)^n = p^n + q^n$. *Then, for n>1, I substituted an arbitrary number, 2. Well, when I substituted it, the result was different.*
R : *How is it different?*
SL : *This is mom. If n=1, the statement is true, but if n>1, the statement is false.*
R : *And then the conclusion?*
SL : *So the statement in the problem is not always true.*

One of the indicators of the rechecking stage is that students can implement the results obtained into other related problems. In this case, students with *a low level of abstraction* category implemented the concept of power numbers into the field of science, as in the following interview excerpt:

R : Do you know how to implement exponents in science?
SL I : know mom. Exponents can be used to write units in physics.
R : What does that mean?
SL : In science, density= $\frac{mass}{volume} = \frac{kg}{m \times m \times m} = \frac{kg}{m^3} = kg\ m^{-3}$*. So here, the exponent number is used to write the unit of density,* $\frac{kg}{m^3}$*.*

While the subject had a high level of abstraction category, SH did the stage of understanding the problem by identifying each known piece of information but did not write explicitly on his worksheet. The subject also did the stage of understanding the problem but needed to explicitly write down the number of memorizations that would be used to prove it. SH subject immediately took any integer to be substituted into the form $(p+q)^n = p^n + q^n$. Then, SH carried out the plan by operating on any number that had been substituted. The operation showed that the results of the left and right segments were not the same, so she concluded that the statement in the problem was never true. The results of SH's work show that she can understand and solve problems related to the basic concepts of exponents but does not write in detail on her worksheet, as shown in Figure 3 and the following interview excerpt.

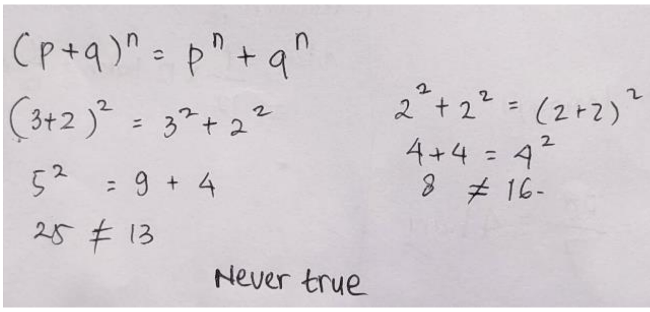

Figure 3. Result of SH work

R : Why did you write very briefly like that?
SH : Because I already understand the meaning of the problem, ma'am. So I do not need to write the known and the question.
R : Then why did the numbers 2, 3 and 4 suddenly appear?
SH : I took an arbitrary number, then substituted it into the form $(p+q)^n = p^n + q^n$ *to prove the truth of the claim, but it turns out that the statement is not always true. So I wrote that it was never true.*
R : That is it. Then, after that, did you not check again?
SH : I did not do it because I was sure the answer was correct.
R : Ok. Then, do you know the benefit or application of exponents?
SH : I know, ma'am. In high school, exponent numbers were used in science, for example, in writing units. 1 liter $= 10^{-3} m^3 = 1\ dm^3$

Based on the results of the exploration of low-level abstraction and high-level abstraction students, it can be seen that both levels of students not only understand the concept of power numbers but also know the benefits of studying power numbers in the field of science. The differences between the two levels are presented in Table 1.

Table 1 shows that both levels of students perform the understanding problem stage by identifying each piece of information in the test problem. Low-level abstraction, students identify each piece of information in detail and then write it on their worksheet. However, high-level abstraction students only store it in their brains, so they do not write it explicitly like low-level abstraction students. The activity of understanding the problem can be shown by structuring the problem based on basic definitions (Kariadinata, 2021).

Furthermore, students engage in understanding the problem by analyzing and organizing its structure and articulating the relationship between the ideas of exponential numbers and integers. The pupils' linking of many concepts demonstrates their comprehension of the test's intended goal. The capacity of students to organize problems according to fundamental definitions indicates their comprehension of the issue (Kariadinata, 2021).

Then, when making plans, students use memorization with mathematical symbols to facilitate the problem-solving process. Low level of abstraction, students write in detail the symbols that will be used to solve the problem, but at a high level of abstraction, students need to write down the memorization that will be used because they already have it in their minds. The high level of abstraction student directly substituted an arbitrary number into the form $(p+q)^n = p^n + q^n$. Solving using mathematical symbols or in the form of an arbitrary number shows that both levels of students can understand the meaning of abstract mathematical symbols. Therefore, it can be said that students can translate or represent mathematical symbols (Shodikin et al., 2023).

Students develop problem-solving strategies prepared when understanding the problem or planning to carry out the solution process (Akben, 2020; Fitriaani et al., 2020; Szabo et al., 2020). Students solve by using alternatives or developing other strategies to get a solution (Kariadinata, 2021; Yayuk et al., 2020). In this case, in low-level abstraction, students substitute the results of the memorization at the stage of making a plan into the form $(p+q)^n = p^n + q^n$; in this case, students substitute various types of integers as shown in Figure 2 to test the truth of the claim. Meanwhile, at a high level of abstraction, students only substitute two types of numbers and then give a conclusion. Cognitive activities are required to validate a mathematical assertion (Faizah et al., 2020). Additionally, the validity of a claim must be mathematically demonstrated through the use of suitable concepts and methods (Hamdani et al., 2023).

Table 1. Students' Abstraction Thinking Level

Stage Problem-Solving	Abstraction Level	
	Low level of abstraction	High level of abstraction
Understanding problem	Students identify each piece of information in the problem and then write it on the worksheet. "$p, q, n \in w$ dan $n \geq 1$ dengan $w =$ whole number"	Students identify each piece of information in the problem but do not explicitly write the results of their understanding on the worksheet.
Devising a plan	Students formalize each piece of information in mathematical symbols, then take an arbitrary number corresponding to the result of understanding the problem.	Students do not explicitly write down the formulation to be used, but they directly substitute an arbitrary number for "$(p+q)^n = p^n + q^n$"
Carrying out the plan	Students perform number operations based on the results of the memorization that has been compiled at the stage of making a plan and understanding the problem.	Students perform number operations because they already understand the meaning of the problem they are working on.
Looking back	Students double-checked by normalizing with other numbers and then made conclusions based on the results of substituting several numbers. The conclusion is in the form of ". If the power is (n=1), then the statement in the problem is always true, but if the power is (n>1), then it is always false". Students also check by implementing the concept of exponent numbers or power numbers in the field of science, in this case, on density in physics.	Students do not check again because they feel confident with their answers. Students immediately write the conclusion in the form of "never true". Students can implement the concept of exponent numbers with the field of science, namely units, for example 1 liter = $10^{-3}m^3 = 1\ dm^3$

Students recheck each stage of the solution that has been done and then provide conclusions. The results of student solutions show that the claim in the problem is not always true because it depends on the type of integers substituted into the form $(p+q)^n = p^n + q^n$. Students review each step of the solution and then provide conclusions. In Polya's problem-solving, the rechecking stage can be characterized by activities: determining conclusions, whether there are other alternatives to get results, or checking the accuracy of the answer to the question (Purnomo et al., 2024). Conversely, it is crucial to review responses in order to assess the effectiveness of problem-solving solutions during the mathematical problem-solving phase (Retnowati et al., 2018).

Students at both levels are not only able to test the truth of a statement through Polya's problem-solving stage, but they also understand the benefits of learning the material of power numbers. Students said that power numbers can be used in science, especially physics, to write units or densities of substances. This aligns with the statement that science learning is supported by mathematical skills and knowledge (Fitri & Syafriani, 2024; Mutambara & Tsakeni, 2022).

Problem-solving is a strategic competency characterized by the comprehension of concepts, the selection of methodologies, the application of solving strategies, and the utilization of models (Sa'adah & Faizah, 2022; Tania et al., 2024). This aligns with Savaş et al. (2023) findings, who assert that abstraction may manifest in student activities by conceptualizing mathematical concepts as independent entities, thereby establishing connections to other domains through specific processes and methodologies.

In this instance, the high level of abstraction can be termed Contextualized word problems, which encompass substantial contextual information about the problem while lacking explicit details regarding the problem-solving process, resulting in a less detailed presentation. Decontextualized arithmetic refers to a low level of abstraction that offers explicit and detailed instructions on the required actions (Rich & Yadav, 2020). Abstraction understood as decontextualization, necessitates careful consideration due to the significant differences between axiomatic systems and practical applications in mathematics (Ferrari, 2003).

Conclusion

Based on the study results, there are differences in the abstraction thinking process of low-level and high-level students. Low abstraction level students perform problem-solving stages, such as identifying any information contained in the problem and then writing the results of problem identification into the worksheet; using a mathematical symbol and then taking an arbitrary number; performing arithmetic operations based on the results of memorization at the stage of making a plan; and checking again by normalizing with another number then making a conclusion. Meanwhile, the high abstraction thinking level students identified every piece of information contained in the problem but did not write it on the worksheet, substituted any number into the form $(p+q)^n = p^n + q^n$; performed number operations and algebraic operations because they already understood the meaning of the problem; and did not do a detailed recheck because they were sure of their answer. Both level students can understand the benefits of power numbers in the field of science because power numbers can be used to write units in physics.

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Author Contributions
Several people contributed to the completion of this research. The primary author contributed the topic, principal ideas, and requisite materials, whereas the other authors were tasked with devising and structuring the research methodologies. All authors collectively assumed responsibility for data collection, tabulation and analysis, the review process, and paper composition.

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Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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