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Research Article

Epistemological Obstacles in the Process of Learning Mathematical Abstraction: A Systematic Literature Review

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Abstract.

This study aims to analyze students' mathematical abstraction abilities as epistemological obstacles in mathematics learning over the past ten years (2015–2024). A total of 65 articles were collected from the ERIC, Scopus, and Google Scholar databases, of which 27 employed a didactical design research approach. The most commonly encountered learning obstacles were epistemological (55%), followed by didactical (24%) and ontological obstacles (21%). The main difficulties experienced by students included challenges in understanding concepts, performing mathematical representations, applying procedures, and solving problems. Epistemological obstacles in the process of mathematical abstraction were identified through students' tendencies to unconsciously reduce levels of abstraction. These reductions occurred in three interpretations of abstraction levels: the relationship between the thinker and the object of thought, the dual nature of objects and processes, and the complexity involved in understanding mathematical concepts. The findings highlight the critical need to address abstraction-related difficulties to support effective mathematics learning.

Keywords: epistemological obstacles, mathematical abstraction, systematic literature review

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1. INTRODUCTION

One of the abilities that needs to be mastered by students in the mathematics learning process at school is the ability to perform mathematical abstractions. This ability is a basic ability that can help students to rebuild mathematical concepts into new structures in the context of daily life (1). It can be said that mathematical abstraction ability is the ability to think abstractly by generalizing problems in daily life (2). Piaget (2007) classifies abstraction into three forms, namely empirical abstraction, pseudo-empirical abstraction, and reflective abstraction (3). Other abstraction experts, namely Mitchelmore and White (2007) broadly divide abstraction into two, namely empirical abstraction and theoretical abstraction. Empirical abstraction is the process of abstraction that occurs based on real experience or a person's social experience, while theoretical abstraction is an effort to reconstruct a concept based on a theory or knowledge that has been previously possessed into a new concept (4).

Ciffareli (1996) states the ability of reflective abstraction in solving problems into several stages, namely recognition, representation, structural abstraction, and structural awareness (5). In the introduction stage, students can recall and identify previous activities that are in accordance with the problem they are facing (6). The representation stage shows the student's ability to transform problems and problem-solving ideas into their mathematical models (notation, symbols, sentences, tables, and graphs) (7). The next stage is structural abstraction where students are able to solve problems using strategies that are arranged based on previous ideas (8). The last stage is structural awareness where students can demonstrate their ability to consider the results of their chosen problem-solving strategy (3).

Findings from previous studies show that there are still many students in Indonesia who have difficulty in carrying out the mathematical abstraction process. Research conducted by Apriyani (2021) stated that most of the secondary students are still used to concrete objects so that it is difficult to carry out the abstraction process (9). Research by Khasanah et al., (2021) stated that students still have difficulty understanding a concept, cannot determine the right formula, and have difficulty in connecting between concepts (10). Anwar et al., (2022) affirmed in his research that in the process of abstraction, students still have difficulty in making mathematical models and using a mathematical concept (11). In addition, research by Wijayanti & Susanti (2021) shows that students still need to be trained in developing problem solving plans, including conducting mathematical proofs (12).

The ability of mathematical abstraction is related to the ability to think critically, reflectively, and reasoning skills of students. Obstacles in carrying out the mathematical abstraction process are also an obstacle in the learning process or commonly referred to as learning obstacles. Guy Brosseau (2002) explained in his book, there are three types of learning obstacles, namely 1) Ontogenic obstacles, 2) Epistemological obstacles, and 3) Didactic obstacles. Ontogenic obstacles are obstacles that occur due to the limited development of students' thinking maturity, including in this case are mental readiness and student learning readiness. Epistemological barriers are learning barriers that occur due to the limitations of knowledge or concepts that students have. Didactic obstacles arise as a result of the inaccuracy of the learning system implemented (13).

Based on this presentation, various epistemological obstacles were found in learning activities, such as lack of understanding of students' basic concepts, difficulty in translating problems in mathematical models, difficulty in formulating solution strategies, and inability to associate between appropriate concepts. This show that there have been learning obstacles at several levels of the mathematical abstraction process. Therefore, in this study, it will be studied more deeply about the epistemology learning obstacles that occur in students when carrying out the mathematical abstraction process using the systematic literature review method to find the right didactic design to overcome these obstacles through further researches.

1.1. Purpose

This study was conducted to analyze epistemological obstacles that occur in students when carrying out mathematical abstraction processes based on mathematics learning research conducted in the last ten years (2015 – 2024). Furthermore, this study will answer some of the questions below.

1.2. Research question

RQ1: What are the learning obstacles and learning difficulties encountered in research with the topic of mathematical abstraction?

RQ2: What are the theories or indicators used in research with the topic of mathematical abstraction?

RQ3: How epistemological obstacle were happened in the process of mathematical abstraction in mathematics learning?

2. METHOD

In this study, a systematic review was carried out on articles published in international journals and/or national journals in the Scopus, Eric, and Google Scholar databases from

2015 to 2024. A systematic review was chosen because it can imply more thoroughly, objectively and can be redeveloped than a conventional literature review (14). Systematic literature review is designed to be able to answer research questions transparently. The flow of this research consists of identifying, selecting, analyzing, and synthesizing information from published articles. Related to transparency, credibility, and consistency, this research flow follows the guidelines *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA).

2.1. Eligibility criteria

1. The analyzed articles are articles published in national and international journals from the Scopus, Eric, and Google Scholar databases.

2. The analyzed articles are articles published in the range of 2015 to 2024.

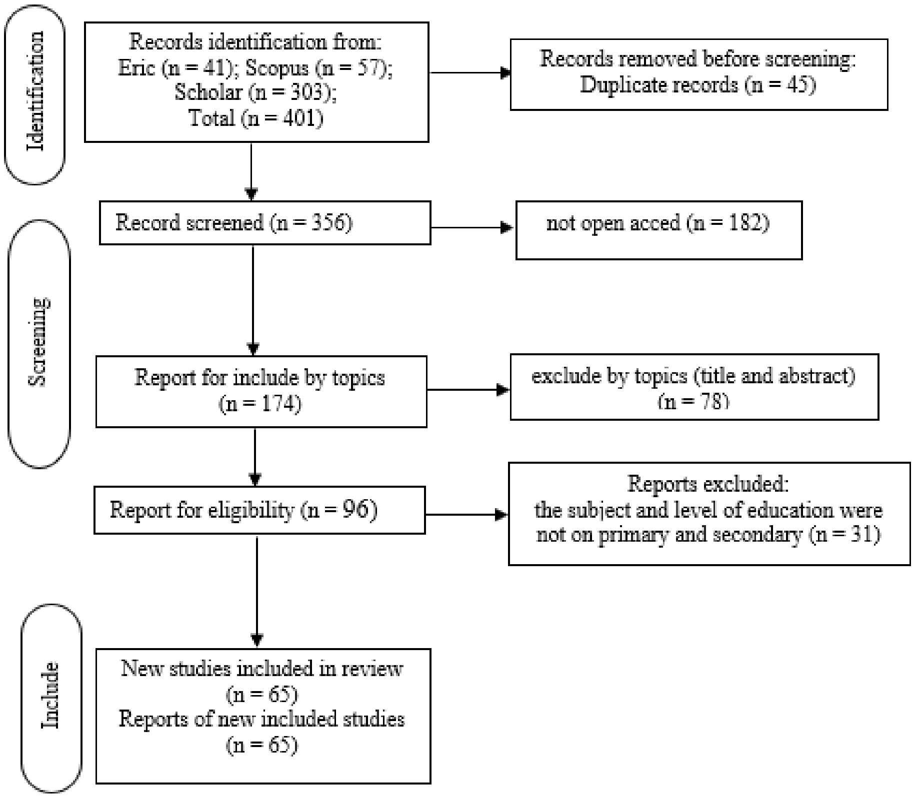
3. The analyzed articles are articles relevant to mathematics learning research.

4. The articles used mention subjects ranging from elementary to intermediate levels

5. The article used mentions the level of education ranging from elementary to secondary level.

2.2. Search and selection process

Searches are done manually by visiting the journal database site or page and using the search engine Harzing's Publish or Perish. The researcher sorted starting from the year, title, number of citations, and keyword restrictions. There are three keywords used in the search and collection process of articles in the Eric and Google Scholar databases, namely *"mathematical abstraction," "mathematical learning obstacles,"* and *"didactical design research."* The keywords used in the Scopus database are *"mathematical abstraction or didactical design research"* and "*mathematical learning obstacles or didactical design research."* The flow of this research is illustrated in the flow diagram as follows:



3. RESULTS AND DISCUSSIONS

3.1. Data extraction

The data extraction process is carried out using coding techniques to analyze the data systematically. The data extracted in this study were the year of publication, research subject, level of education, research method, research design, and material used in the research. The results of data extraction are presented in the form of tables, narratives, and diagrams as follows:

The table shows the research trend with the highest mathematical abstraction topic in 2018 and 2020, then declined sharply in 2021 and began to rise in 2022 and 2023. As for the most used research methods, namely qualitative methods with several research designs, including qualitative approach (8 articles), descriptive qualitative (8 articles), case study design (8 articles), task-based interview (2 articles), direct interview (1 article), didactical design research (28 articles), and grounded theory (1 article). Another method is quasi-experiment with several research designs, namely random pre-test post-test

TABLE 1: Data extraction results.

Year	Sum	Subject	Sum	Level of Education	Sum	Research Methods	Sum
2015	1	Preliminary students	1	Nursery Education	1	Qualitative	56
2016	2	Grade 1-6 students	14	Primary Education	13	Development	3
2017	7	Grade7-9 students	30	Secondary Education	35	Mix method (Qualitative and Quantitative)	4
2018	12	Grade 10-12 students	16	Upper Secondary education	16	Quasi Experiment	4
2019	9	General student	5				
2020	13						
2021	6						
2022	7						
2023	9						
2024	2						

with control design, scientific approach, teaching experiment design, and one group post-test no control design.

The next data extracted is the material (subject) used in the research. Based on the analysis, the most frequently used materials in research with the topic of mathematical abstraction are two-dimensional figure as many as 18 articles, then algebra as many as 12 articles, geometry as many as 9 articles, and fractions as many as 5 articles. Some of the other materials used in the research with the topic of mathematical abstraction are presented in the following diagram.

3.2. What are the learning obstacles and learning difficulties found in the research with the topic of mathematical abstraction?

Of the 65 articles analyzed in this study, 27 of them are studies with didactical design research. After analysis, the learning obstacles experienced by students in the didactical design research were 10 articles mentioning ontogenic obstacles (21%), 26 articles mentioning epistemological obstacles (55%), and 11 articles mentioning didactical obstacles (24%). The percentage of this type of learning obstacle is shown in the following pie chart:

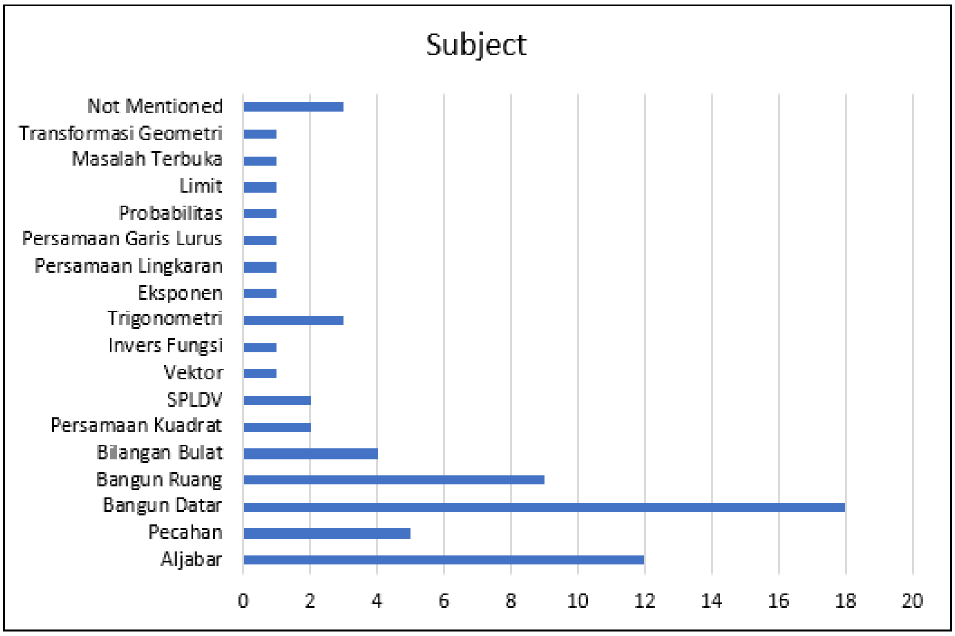


Figure 1: Subjects used in the research with the topic of mathematical abstraction.

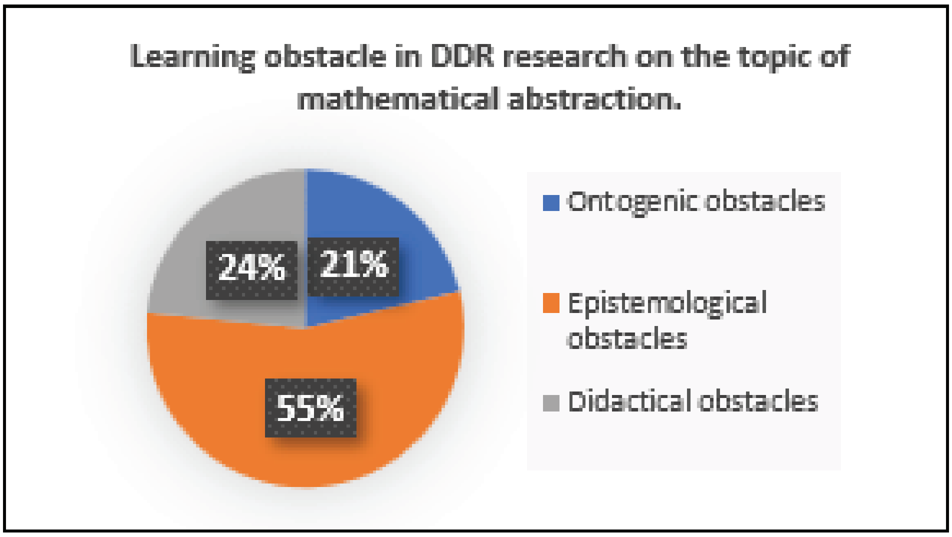


Figure 2: Learning obstacle in DDR research on the topic of mathematical abstraction.

Based on the diagram, it is known that epistemological obstacle is the most dominant obstacle (55%). This shows that students' limited knowledge about mathematics is the biggest inhibiting factor in the learning process. Furthermore, the learning difficulties of students contained in this study will be shown, both in DDR research and other research methods as follows:

Some of the learning difficulties experienced by students are, difficulties in understanding concepts (n = 30) including understanding of nature, elements, characteristics, and patterns of arrangement. Furthermore, difficulties in representation (n = 23) such as

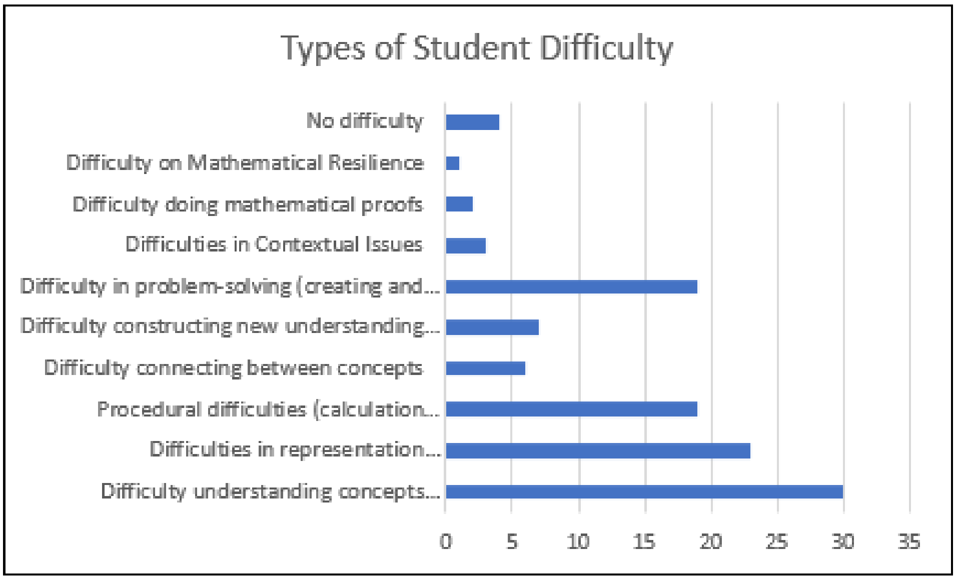


Figure 3: Types of student difficulty.

interpretation of images, graphs, models, and spatial ability. Procedural difficulties (n = 3) are calculation operations, including addition, subtraction, multiplication, division, area, circumference, and so on. Other difficulties were difficulty in connecting concepts (n = 6), difficulty in constructing new understandings (n = 7), difficulties in problem solving (n = 19) including creating and implementing solution strategies, difficulties in contextual issues (n = 3), difficulties in conducting mathematical proofs (n = 2), and difficulties related to mathematical resilience (n = 1).

From the many learning difficulties experienced by these students, it can be concluded that there are four most common learning difficulties, namely students have difficulty understanding a concept (n = 30), difficulty in making mathematical representations (n = 23), difficulties in procedures, and difficulties in solving problems (n = 19). However, in this study, there are also several research results that show that there are no significant difficulties experienced by students (n = 3).

3.3. What are the theories or indicators used in research on the topic of mathematical abstraction?

There are several theories used in research on the topic of mathematical abstraction, namely, the RBC+C abstraction model (Herskowitz, Schwarz, & Dreyfus), APOS theory (Dubinsky, 1991), levels of reflective abstraction (Cifarelli, 1988), theory of Karadag, empirical abstraction & reflective abstraction (Piaget, 2001), indicators of abstraction capabilities (Battista, 2007), as well as a combination of several theories such as the combination of Piaget's (1972, 2001), Battista's (2007), Gray's (2007), Herskowitz's, Schwarz's, & Dreyfuz's (2001), Ozmantar's & Mnaghan's (2007), and Steffe's & Cobb's (1988); as well as a combination of Skemp (1986), Piaget's (1970), and Dreyfus' (1991). These theories are presented in the following diagram.

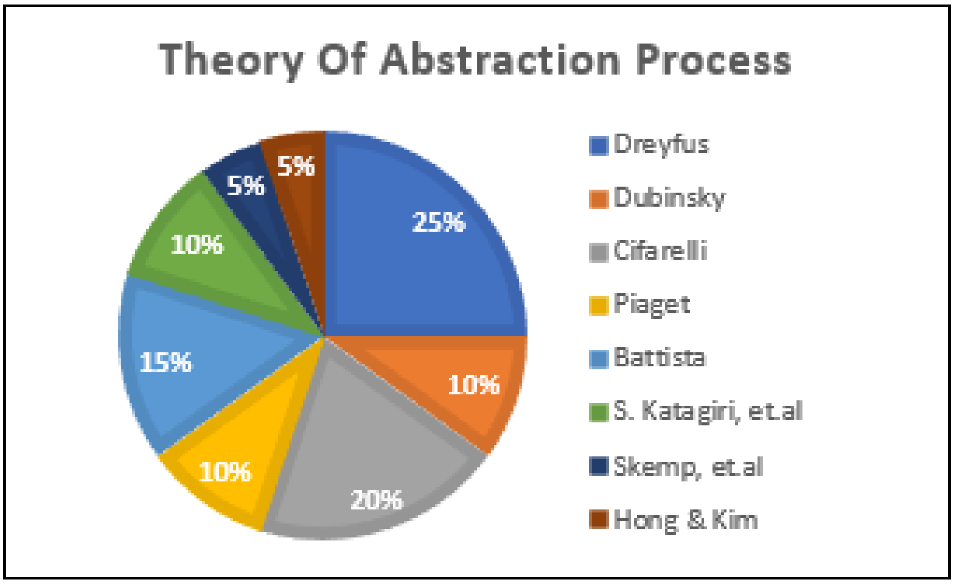


Figure 4: Theory of abstraction process.

3.3.1. RBC+C Abstract Model (Herskowitz, Schwarz, & Dreyfus)

There are three actions in this model, namely, *Recognizing* or also known as recognition, which is an individual's awareness of what kind of initial knowledge is needed, including formal or informal information that a person has obtained before. Next *Building-with* or building is an individual's effort to use known information to build a solution that can be used on a problem. These cognitive actions rest on other cognitive actions (15). The third action is *construction* or construct. Namely an effort to change some of the known structures so that they can form new structures. The last action is *consolidation* or consolidation which is a follow-up action of the construction action, namely the need for new structural improvements (16).

3.3.2. APOS Theory (Dubinsky, 1991)

There are four stages in this theory, namely: *Action Level* (Action level), *process* (process), *Object* (object), and *schema* (schema). Deep *Action Level*, students perform actions only limited to applying existing algorithms. Students need detailed steps to transform (15). If the action is carried out repeatedly and can be reflected, then the action can be internalized as a process. At this stage, students have been able to represent and reflect on the steps of a process. When an individual reflects a process applied to a particular process, then becomes aware of the process in general and performs a transformation (either in action or process), this process can be considered an object (17). Meanwhile, at the schema level, it shows involvement in the organization of the object, which is a thematization of the diagram into an object.

3.3.3. Levels of Reflective Abstraction (Cifarelli, 1988)

There are four levels of reflective abstraction according to Cifarelli (1988), including *Recognition,* at this level students can remember activities that have occurred before based on the situation they are facing. The second level is *representation* (representation). At this level, students can solve the problems they are facing using tools such as diagrams, tables, and others. The next level is structural abstraction. At this level, students are able to project and rearrange their concepts into new concepts. The last level is structural awareness where students can build new concepts without the need to complete the whole procedures and can anticipate the concepts they build (18).

3.3.4. Indicators of Abstraction Capabilities (Battista, 2007)

There are four levels of mathematical abstraction according to Battista, namely, 1) *Perceptual abstraction*. The process that occurs in this abstraction is an effort to recognize previous experiences to solve the problems faced (19). 2) *Internalization*, which is the process of representing thoughts in the form of symbols, words, or diagrams. In addition, at this level it is also capable of solving or manipulating problems (20). 3) *Interiorization*, which is the process of collecting, compiling, developing, and coordinating concepts into new understandings or new knowledge. 4) Second-level of interiorization, which is an effort to generalize new knowledge in different contexts (21).

3.3.5. Theory of Karadag, S. Katagiri (2004) & J. Mason, L. Burton, & K. Stacey (2010)

Research that uses this theory is research by Iswari et.al., (2019) and Putri et.al., (2021). There are four stages in abstracting in this theory, namely *observation of patters* (pattern observation), *Specialization* (specialization), *Generalization* (generalization), and *conjecturing* (suspected) (22). The pattern observation stage is the stage where the subject solves the problem by observing the pattern. The specialization stage occurs when the subject solves a problem by looking at a specific example. The generalization stage is the process of describing a pattern into its general form. Meanwhile, the guessing stage is the process of testing and re-examining assumptions based on the facts found. This process is carried out to find out whether the assumptions taken are correct and correct (23).

3.3.6. Hong & Kim

Research conducted by Hong and Kim (2016) combines several theories to compile indicators of mathematical abstraction. The theories used include the theory of Piaget (1972, 2001), Battista (2007), Gray & Tall (2007), Herskowitz, Schwarz & Dreyfus (2001), Ozmantar & Monaghan (2007), and Steffe & Cobb (1988). Some of the actions formulated by Hong and Kim in carrying out the abstraction process are 1) Recognizing mathematical structures through perceptual abstraction, 2) Applying mathematical structures through internalization, and 3) Constructing new structures through interiorization (24). In the first action, Students are aware of the need for mathematical structures to solve problems, students can remember the mathematical structures that have been studied previously including knowledge, concepts, and mathematical principles, and students can also recognize and identify elements related to problems based on their own intuition.

Then in the second action, students can simplify the problem into simpler forms using mathematical relationships and structures. Students can also actively introduce, utilize, and apply previously learned mathematical structures to solve problems. In the last act, students can solve problems by generalizing mathematical concepts. In addition, students can form new mathematical knowledge and structures in solving problems. Students are also able to generalize problems into different real-life contexts, as well as being able to develop new structures based on previously learned mathematical structures.

3.3.7. Combination of Skemp (1986), Piaget (1970), & Dreyfus (1991)

The research conducted by Nurhasanah, et al. (2017) combined theory from Skemp (1986), Piaget (1070) and Dreyfus (1991). This combination combines empirical abstraction and theoretical abstraction. The abstraction process that occurs is that students can identify the characteristics of objects through direct experience and identify the characteristics of manipulated or imagined objects. In addition, students can also generalize and represent problems into symbols or mathematical language, create relationships between processes or concepts to form new understandings, and apply concepts into appropriate contexts (25).

3.4. How is the epistemological obstacle in the process of mathematical abstraction in mathematics learning?

Epistemological learning obstacles arise due to limitations in students' knowledge and understanding of something (concept, problem, or other) (Guy, 2002). This obstacle is closely related to students' abilities, namely comprehension and procedural abilities. The process of understanding a concept, up to solving a problem is part of the mathematical abstraction process. Thus, students' difficulties in carrying out the mathematical abstraction process can be an epistemic obstacle for students.

In line with that, Orit Hazzan and Rina Zazkis (2005) explain in their paper how a person's level of abstraction can be reduced. Reducing the Level of Abstraction itself is a theoretical framework that examines student behaviors in handling abstraction according to its level. This leads to a situation where students are unable to develop and/or restructure the concepts used in solving a particular problem (26). Therefore, they unconsciously reduce the level of abstraction of concepts used to create new concepts. Indicators of reducing the level of abstraction based on the three interpretations of the level of abstraction according to Orit Hazzan and Rina Zazkis are presented in the following table.

Some of the obstacles experienced by students in performing mathematical abstraction found in this study are, in the interpretation of abstraction as the quality of the relationship between the object of thought and the person who thinks, students cannot see the relationship between the objects observed, or students are aware of the characteristics of the object observed but cannot complete the actions that have been taken

Table 2: Indicators of reducing the level of abstraction according to Orit Hazzan and Rina Zazkis.

No.	Interpretation of Abstraction Levels	Abstraction Level Reduction Indicator
1.	Abstraction as the quality of the relationship between the object of thought and the person who thinks.	Students cannot understand the assignments assigned to them. Students abandon unrecognized objects and choose to do what is familiar and understood.
2.	Abstraction as a reflection of the duality of process-object.	Students solve problems without analyzing the properties of mathematical concepts (students tend to calculate rather than pay attention to the structure of numbers in their form of transformation).
3.	The abstraction process uses the complexity level of mathematical thinking concepts	The student cannot follow any standard rules to solve the problem he is facing so they miss something more complex.

to manipulate the object. Students prefer to use information from problem statements then process it in mental actions using their previous knowledge in solving problems.

Then in the second interpretation, which is abstraction as a reflection of the duality of process-object, students have difficulty explaining signs and other elements in a concept and only understand the general form. In addition, students cannot understand new information in new situations. Students also do not remember the details of previous knowledge. Students solve problems based only on a plan without specifying a strategy or method of completion. In terms of the use of complexity of mathematical concepts, students still often use concrete thinking in abstracting. Students often miss things that can be used in solving problems because they cannot follow the truth of the rules of solving mathematical problems.

4. CONCLUSION

Based on this presentation, it can be concluded that systematic literature reviews were carried out on 65 articles from 2015 to 2024, with subjects used ranging from preliminary students to grades 10-12 students. The level of education used is starting from Nursery education to upper secondary education. Some of the research methods used are qualitative methods, development, mixed methods (qualitative and quantitative) and pseudo-experimental methods. In qualitative research, the most common approach is qualitative with a didactical design research approach (27 articles). The most used mathematical materials in mathematical abstraction research are flat figures, algebra, spatial figures, and integers.

This study also answers several research questions. In the first question, the results were obtained that of the 65 articles used, 27 of them were research with didactical design research, so that it was known that the most learning obstacles experienced by students were epistemological obstacle (55%), didactical obstacle (24%), and ontogenic obstacle (21%). This shows that students' limited knowledge about mathematics is the biggest inhibiting factor in the learning process. In addition, it is also known that the most dominant types of student difficulties are difficulties in understanding concepts, difficulties in making representations, difficulties in procedural procedures, and difficulties in problem solving.

The theories used in mathematical abstraction research include the RBC+C abstraction model (Herskowitz, Schwarz, & Dreyfus), APOS theory (Dubinsky, 1991), levels of reflective abstraction (Cifarelli, 1988), theory of Karadag, empirical abstraction & reflective abstraction (Piaget, 2001), and indicators of abstraction capabilities (Battista, 2007). In addition, some studies also use a combination of theories such as the combination of Piaget's (1972, 2001), Battista (2007), Gray's (2007), Herskowitz's, Schwarz's (2001), Ozmantar's (2007), and Steffe's (1988); as well as a combination of Skemp's (1986), Piaget's (1970), and Dreyfus' (1991). Among these theories, the most used theory is the RBC+C abstraction model by Dreyfus. Then this study also shows that epistemic obstacles in the process of mathematical abstraction occur when students unconsciously reduce the level of abstract concepts used in compiling mathematical concepts.

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