JIPM: Jurnal Ilmu dan Pendidikan Matematika
Vol.1 No.2 Oktober (2023)
e-ISSN: 2988-7763
DOI: 10.33830/hexagon.v1i2.5356

Conceptual Understanding and Reasoning of Students with Dyscalculia: A Literature Review

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ARTICLE INFO

Article history:
Received : July 13th, 2023
Revised : August 24th, 2023
Accepted : September 30th, 2023
Available : online October 31st, 2023

Kata Kunci:
Diskalkulia, Pemahaman Konseptual, Penalaran

Keywords:
Dyscalculia, Conceptual Understanding, Reasoning

ABSTRACT

Dyscalculia is a specific learning condition that affects one's understanding and manipulation of numerical concepts. Conceptual understanding is one of the components of mathematics proficiency that can be developed through reasoning skills. However, neither the conceptual understanding nor the reasoning abilities of students with dyscalculia have been thoroughly described. The objective of this systematic review of the relevant scientific literature is to identify and analyze existing evidence regarding the conceptual understanding and reasoning skills of students with dyscalculia by using the following procedures: (1) developing a research question; (2) selection criteria; (3) developing the search strategy; (4) study selection process; (5) appraising the quality of studies; and (6) synthesizing results. The articles were obtained from various online databases. Subsequently, a meticulous screening process was undertaken based on predetermined selection criteria, and the quality of the articles was appraised, resulting in twenty articles for further analysis. It was discovered that students with dyscalculia lacked conceptual understanding and reasoning skills, which could present them with a variety of difficulties, such as processing mathematical facts and further developing their mathematical skills.

INTRODUCTION

Mathematics plays a significant role in human existence and is utilized in numerous fields. It has been determined that the strategies and abilities gained from mathematics are necessary not only for academic success but also for effective functioning in day-to-day living (Aprinastuti et al., 2020; Kißler et al., 2021; Kunwar & Sharma, 2020; Lazo-Amado et al., 2022; Liu et al., 2022; Ziadat, 2022). This realization comes as no surprise, given the central role mathematics plays in almost every aspect of our lives (Hodaňová & Nocar, 2016). This underscores the significance of mathematics education in institutions as well. Mathematics education plays a crucial role in preparing students for their future roles in society and the economy, as well as for their personal growth (Bakker et al., 2021)

Since mathematics cannot function without the application of extremely high levels of mathematical skill and knowledge, the primary reason it is taught and practiced in schools is to benefit society (Aprinastuti et al., 2020; Kißler et al., 2021; Kunwar & Sharma, 2020; Lazo-Amado et al., 2022; Liu et al., 2022; Ziadat, 2022). The ability to perform well in school and in life generally requires a high level of mathematical skills due to the nature of modern society (Lyons & Ansari, 2015; Mitra, 2002; Vanbinst & De Smedt, 2016). It is crucial that students acquire a comprehensive understanding of mathematics, which involves actively constructing novel knowledge from their prior experiences and existing knowledge (National Council of Teachers of Mathematics, 2000). Conceptual understanding is a fundamental component of knowledge, just as it is a part of mathematical proficiency, and it can be developed through various mathematical skills, such as reasoning. Mathematical reasoning skill is important as it serves as a basis for developing new insights and promoting further study, and being able to reason is essential to understand mathematics (Crooks & Alibali, 2014; Hjelte et al., 2020; Nurjanah et al., 2021)

Undoubtedly, the mathematics that an individual acquires during their academic years will have a significant impact on their life (Aprinastuti et al., 2020; Kißler et al., 2021; Kunwar & Sharma, 2020; Lazo-Amado et al., 2022; Liu et al., 2022; Ziadat, 2022). However, 5-8% of school-aged individuals have a learning disability that makes it challenging for them to understand the fundamental concepts of mathematics (Fauzan et al., 2022; Lazo-Amado et al., 2022; Patricia & Zamzam, 2021). This learning disability, known as dyscalculia, along with dyslexia and dysgraphia, is one of the most common learning disabilities among school-aged individuals (Ahuja et al., 2022; Kariyawasam et al., 2019). Dyscalculia is a learning condition that makes individuals who have it face difficulty learning and acquiring basic mathematical skills (Dehghani, 2019; Jannah & Bharata, 2020; Kariyawasam et al., 2019; Kohn et al., 2020; Kunwar & Sharma, 2020). Students with dyscalculia might find it difficult to develop the mathematical skills necessary for mathematics proficiency, as they struggle to fully understand fundamental mathematical concepts (Ahuja et al., 2022; Fauzan et al., 2022; Jannah & Bharata, 2020; K. E. Lewis et al., 2022; Noordin et al., 2020; Patricia & Zamzam, 2021; Vigna et al., 2022; Ziadat, 2022). As one of the components of mathematical proficiency, conceptual understanding and reasoning skills are essential. Therefore, it is necessary to identify these skills in students with dyscalculia."

Understanding the underlying issues that students with dyscalculia face in conceptual understanding and mathematical reasoning may assist teachers in gaining a better understanding of the mathematical skills possessed by these students. These insights can also help teachers determine the type of intervention required for students with dyscalculia to acquire the necessary mathematical skills. Only a handful of literature reviews have been conducted to cover the mathematical skills of students with dyscalculia. According to a study on domain-general cognitive skills in children with dyscalculia, some cognitive domains in children with mathematical difficulties were compromised (Agostini et al., 2022). Another study that examined the domain-general and domain-specific aspects of developmental dyscalculia found that visuospatial working memory and symbolic number processing skills were the best predictors of math ability in children with dyscalculia (Mishra & Khan, 2022). A comprehensive review of the literature on dyscalculia will serve as the foundation for this study, which aims to investigate both mathematical conceptual understanding and mathematical reasoning in students with dyscalculia. This research endeavour is significant in advancing the field of mathematics learning as it seeks to shed light on the specific challenges faced by students with dyscalculia, ultimately contributing to the development of targeted interventions and instructional strategies to enhance their mathematical proficiency.

METHOD

The present study employed a systematic literature review as its research methodology. The objective of this study is to conduct a systematic literature review (SLR) by employing transparent and rigorous research methods (Newman & Gough, 2020). The primary goal of this review is to critically evaluate the existing body of research on the topic under investigation. This study followed the research methods of Aisyah and Juandi (Aisyah & Juandi, 2022), which consist of six steps outlined below.

Develop Research Questions

The following are the study's research questions, formulated based on the study's background:

1. How do students with dyscalculia understand mathematical concepts?
2. What are the mathematical reasoning skills of students with dyscalculia?

Selection Criteria

The next step in the study's procedures was to define the selection criteria. This study employed a rigorous selection process to identify relevant articles that aligned with the research questions. This process involved the application of multiple sets of inclusion and exclusion criteria in the article search process. The purpose of these criteria was to ensure that only articles meeting the predetermined standards were selected for inclusion in the study. Specifically, this study included articles published within the last five years and written in the English language. Using articles published within the last 5 years in academic writing ensures relevance, accuracy, acknowledgment of contemporary contributions, avoidance of repetition, awareness of evolving methodologies, and alignment with journal requirements, all of which collectively enhance the credibility and timeliness of the research. Referencing articles written in English provides access to a diverse body of research, international readership, alignment with academic standards, and enhanced credibility within the global scholarly community. Table 1 displays the selection criteria employed in this study

Table 1. Selection Criteria

	Criteria
Inclusion	1. Articles were the results of primary research published in a journal or proceeding. 2. Articles published from 2019 to 2023. 3. Articles were written in English
Exclusion	1. Chapter book, thesis, brief report, and non-empirical study types 2. Articles published outside of the stated timestamp 3. Articles were not written in English

Developing the Search Strategy

The present study conducted an analysis of academic papers obtained from various electronic repositories, including ERIC (https://eric.ed.gov/), Google Scholar (https://scholar.google.com/), and Crossref (https://www.crossref.org/). The articles were selected using the software tool Publish or Perish and subsequently underwent an intensive review process. The current investigation utilized the search term "dyscalculia" to extract academic papers from various databases. Below are the initial searches for articles on ERIC and Publish or Perish:"

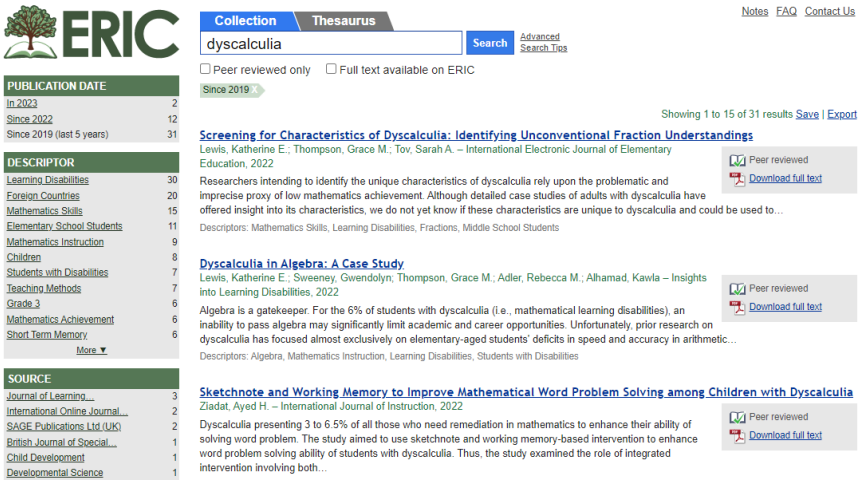

Figure 1. Initial Search on ERIC

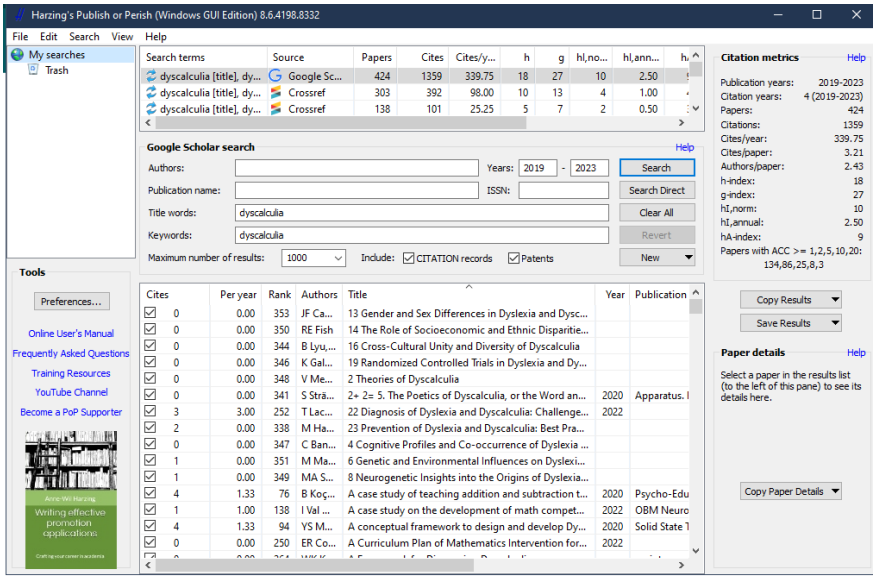

Figure 2. Initial Search on Google Scholar using Publish or Perish

The Study Selection Process

During this study, a search strategy was formulated and implemented. The articles and abstracts obtained through this strategy were subjected to an initial screening process to assess their relevance and adherence to predetermined selection criteria. Following the initial screening process, a comprehensive evaluation of the articles was conducted. Articles that did not satisfy the predetermined selection criteria and were deemed irrelevant were excluded from further analysis

Appraising the Quality of Studies

After the study selection process, the articles were evaluated for quality based on a set of predetermined criteria to determine their relevance to this study. The following are the quality assessment criteria:

AQ1. Is the article the result of primary research?
AQ2. Does the article discuss dyscalculia in the educational domain?
AQ3. Does the article address a research problem relevant to this study?
AQ4. Does the article mention mathematical conceptual understanding and/or reasoning of students with dyscalculia?

Synthesis Result

This study aimed to provide a comprehensive analysis of the mathematical conceptual understanding and reasoning abilities of students with dyscalculia. To achieve this objective, the synthesis procedure was executed in accordance with the research objectives. This study involved a thorough examination of the contents of each article, followed by the identification of the mathematical conceptual understanding and reasoning abilities of students with dyscalculia. These findings were then used to address the formulated research questions.

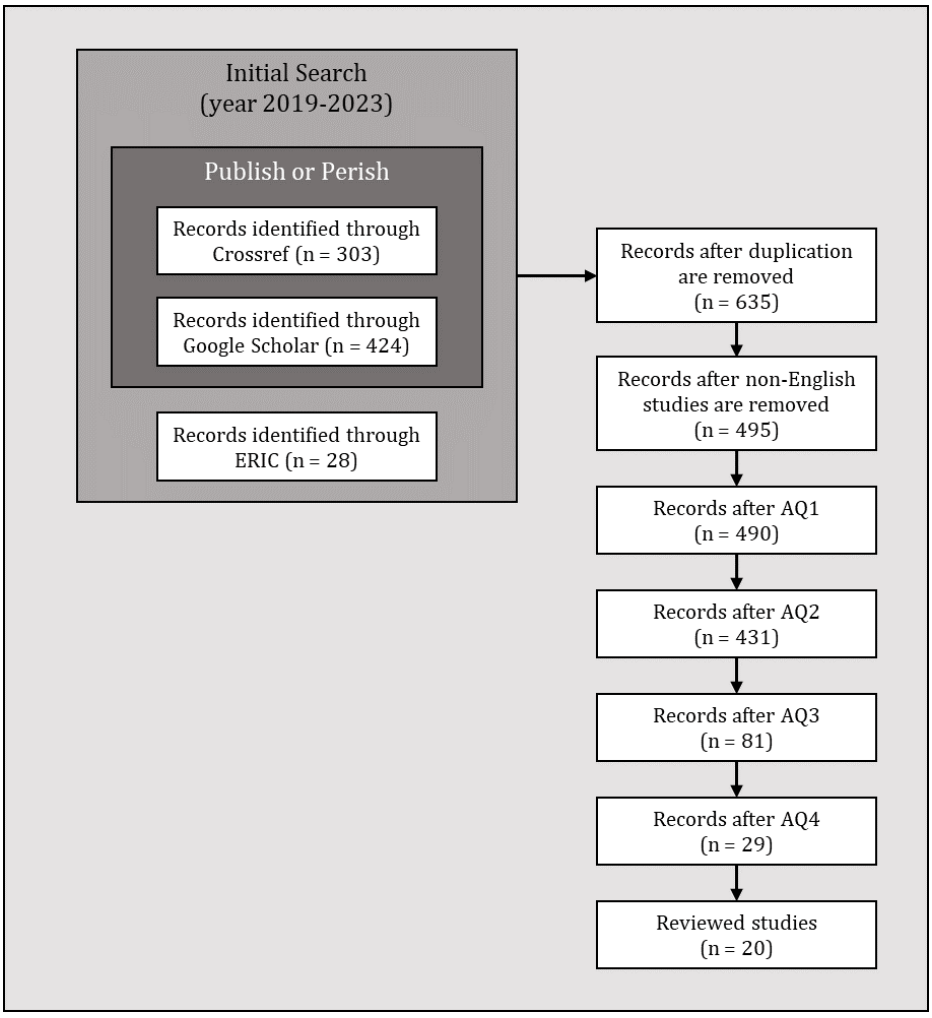

Figure 3. Research Flow

RESULT AND DISCUSSION

Result

A total of twenty articles were found to meet the selection and quality criteria during the selection process. The majority of the studies were conducted at the elementary school level. Among these studies, 40% were conducted in 2022, and half of them used quantitative research methods. The distribution of research locations was relatively uniform, with five studies conducted in Asian countries, four in both North America and Europe, and one each in South America and Africa.

Table 2. Studies Included in the Review

Study	Method	Level	Country
(Erfurt et al., 2019)	Research and Development	Elementary School	Germany
(Dehghani, 2019)	Research and Development	Elementary School	Iran
(Jannah & Bharata, 2020)	Qualitative	High School	Indonesia
(Cheng et al., 2020)	Quantitative	Elementary School	China
(Kohn et al., 2020)	Quantitative	Elementary School	Germany
(Castaldi et al., 2020)	Quantitative	Adult	Italy
(K. E. Lewis et al., 2020)	Qualitative	Adult	USA
(Decarli et al., 2020)	Quantitative	Elementary School	Italy
(Lu et al., 2021)	Quantitative	Elementary School	China
(Firmasari et al., 2021)	Quantitative	Elementary School	Canada
(Kißler et al., 2021)	Qualitative	Elementary School	Indonesia
(Ahuja et al., 2022)	Quantitative	Elementary School	Germany
(K. E. Lewis et al., 2022)	Quantitative	Elementary School	India
(Lazo-Amado et al., 2022)	Qualitative	Adult	USA
(K. Lewis et al., 2022)	Research and Development	Elementary School	Peru
(Vigna et al., 2022)	Mixed Method	Middle School	USA
(Fauzan et al., 2022)	Quantitative	Adult	Italy
(Gut et al., 2022)	Qualitative	Elementary School	Indonesia
(Nkepah & Atanga, 2022)	Quantitative	Elementary School	Poland

Discussion

Mathematical Conceptual Understanding of Students with Dyscalculia

Students with dyscalculia faced difficulties in understanding mathematical concepts, which affected their ability to work with numbers and operate with them (Bugden et al., 2020; Castaldi et al., 2020; Cheng et al., 2020; Decarli et al., 2020; Dehghani, 2019; Erfurt et al., 2019; Fauzan et al., 2022; Firmasari et al., 2021; Jannah & Bharata, 2020; Lazo-Amado et al., 2022; K. Lewis et al., 2022; K. E. Lewis et al., 2020, 2022; Nkepah & Atanga, 2022). This difficulty also extended to solving mathematics problems (Dehghani, 2019; Fauzan et al., 2022). Furthermore, they exhibited unconventional understandings that could be attributed to cognitive differences (K. Lewis et al., 2022; K. E. Lewis et al., 2020, 2022). For instance, they may have unconventional understandings of integer quantities and symbolic notation (K. E. Lewis et al., 2020)

These unconventional understandings among students with dyscalculia may result in difficulties with basic mathematics, not to mention more complex mathematical concepts (Ahuja et al., 2022; Dehghani, 2019; Erfurt et al., 2019; Kißler et al., 2021; K. Lewis et al., 2022; K. E. Lewis et al., 2022, 2022; Nkepah & Atanga, 2022). Dyscalculia can make it challenging to perform a variety of arithmetic and numerical tasks (Ahuja et al., 2022; Dehghani, 2019; Fauzan et al., 2022; Kohn et al., 2020; Vigna et al., 2022) and to apply mathematical concepts in and out of the classroom (Fauzan et al., 2022; Firmasari et al., 2021; Vigna et al., 2022)

In simpler terms, students with dyscalculia demonstrated difficulty in processing numbers (Gut et al., 2022). For example, they made more errors when counting and estimating numbers, comparing numbers, and performing arithmetic operations (Ahuja et al., 2022; Dehghani, 2019; Fauzan et al., 2022; Firmasari et al., 2021; Gut et al., 2022, 2022; Vigna et al., 2022). Additionally, they displayed the use of underdeveloped mathematical strategies, such as verbal and finger counting (Gut et al., 2022). One study categorized the various obstacles faced by students with dyscalculia that impaired their conceptual understanding of mathematics into four groups: spatial disruption, difficulty understanding concepts, difficulty understanding formulas or symbols, and calculation difficulty (Jannah & Bharata, 2020). While

these classifications might be attributed to a lack of understanding of mathematical concepts, unclear instructions from instructors may have also contributed to the challenges faced by students with dyscalculia (Jannah & Bharata, 2020).

Conceptual understanding refers to a comprehensive and practical grasp of mathematical concepts (Crooks & Alibali, 2014; Nurhasanah, 2019). Even though it was not explicitly stated in the majority of the reviewed papers, it is evident that students with dyscalculia lacked conceptual understanding. The fundamental requirement for students to have a solid conceptual understanding was the integration of factual and procedural knowledge. However, students with dyscalculia possessed different factual knowledge than their peers, making it challenging for them to apply their procedural knowledge correctly. For instance, students with dyscalculia had unconventional understandings of the use of mathematical symbols and numbers (K. Lewis et al., 2022; K. E. Lewis et aI., 2020, 2022), hindering their ability to apply them correctly when solving mathematical problems.

The struggles of students with dyscalculia may have had a negative impact on other mathematical skills, such as reasoning and problem-solving. This not only affected their academic performance but also their social lives due to a lack of conceptual understanding. Several studies have been conducted to explore strategies aimed at enhancing conceptual understanding among students with dyscalculia. These strategies include the use of technologies like the mobile application "Kalcal" (Dehghani, 2019) and augmented reality (Lazo-Amado et al., 2022), as well as specialized interventions for students with dyscalculia (Cheng et al., 2020; Erfurt et al., 2019; Fauzan et al., 2022)

Mathematical Reasoning of Students with Dyscalculia

Because dyscalculia makes it challenging for students to understand mathematics, it can also have an impact on their ability to reason (Castaldi et al., 2020, 2020; Fauzan et al., 2022; K. E. Lewis et al., 2022). Students with dyscalculia may struggle with reasoning, particularly in tasks that rely on numerical information, spatial and creative reasoning (Dehghani, 2019; Fauzan et al., 2022). They also lack nonverbal matrix reasoning, a cognitive skill involving the ability to recognize patterns and relationships between visual elements (Lu et al., 2021). Additionally, students with dyscalculia may face challenges in multiplication reasoning, which involves various semantic structures related to multiplication representations, such as repeated addition, arrays, and equal groups (Firmasari et al., 2021)

The mathematical reasoning skills of students with dyscalculia are an understudied area. Out of the 20 studies reviewed, only seven briefly discussed the mathematical reasoning of students with dyscalculia. This could be because students with dyscalculia struggle to comprehend elementary mathematics, leading to the assumption that their other mathematical skills are also lacking. Students with dyscalculia exhibit poor mathematical reasoning, especially in solving problems that require spatial, creative, nonverbal matrix, and/or multiplication reasoning (Dehghani, 2019; Fauzan et al., 2022; Firmasari et al., 2021; Lu et al., 2021). Several studies have explored interventions to enhance mathematical reasoning skills among students with dyscalculia, including the use of "Kalcal" (Dehghani, 2019) and abacus training in the mathematics classroom (Lu et al., 2021). It is important to note that the mathematical reasoning abilities of students with dyscalculia vary depending on the severity of their condition. As Jannah & Bharata (2020) stated, students with dyscalculia, like students in general, have different strengths and weaknesses, leading to distinct categories.

CONCLUSION

In conclusion, this study has explored the challenges related to conceptual understanding and mathematical reasoning in students affected by dyscalculia. The comprehensive review of literature and empirical evidence has underscored the significant obstacles these students face, ranging from basic arithmetic to broader mathematical applications. This study emphasizes the need for tailored interventions and instructional approaches to address the unique needs of students with dyscalculia. Furthermore, it highlights the importance of clear instructions in mathematics education.

This research contributes to our understanding of dyscalculia, shedding light on its impact on conceptual understanding and mathematical reasoning. It is hoped that these insights will inform the development of more effective support strategies, promoting inclusivity in mathematics education. Continued research in this field is essential to further explore dyscalculia and enhance the support available to individuals affected by it.

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