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Persistent Hurdles: A Systematic Review of Limit Concept Misconceptions in Undergraduate Calculus

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ABSTRAK

Konsep limit berfungsi sebagai fondasi kritis untuk kalkulus dan analisis matematika, sekaligus menjadi titik transisi penting menuju pemikiran matematika yang abstrak dan formal. Namun, mahasiswa secara global menghadapi kesulitan yang signifikan dan berulang dalam memahami esensi konsep ini. Tinjauan literatur sistematis ini bertujuan untuk menyintesis bukti-bukti empiris guna mengidentifikasi jenis, pola, dan faktor penyebab miskonsepsi serta kesulitan yang dialami mahasiswa dalam memahami konsep limit. Pencarian sistematis dilakukan pada database Scopus, Web of Science, ERIC, dan Google Scholar untuk studi empiris yang diterbitkan antara tahun 2001 hingga 2024. Proses seleksi dan ekstraksi data mengikuti protokol PRISMA. Data dari studi yang *included* dianalisis menggunakan analisis tematik, yang menghasilkan 30 studi yang memenuhi kriteria kelayakan. Sintesis dari 30 studi mengungkapkan pola miskonsepsi yang persisten, terutama pemahaman limit sebagai proses dinamis yang tidak terselesaikan, penyamaan limit dengan nilai fungsi, serta kesulitan mendalam dengan representasi berganda dan definisi formal epsilon-delta. Faktor penyebabnya bersifat multidimensi, meliputi aspek kognitif (intuisi sehari-hari, pengetahuan prasyarat lemah), epistemologis (keyakinan instrumentalis tentang matematika), dan pedagogis (pengajaran yang terlalu prosedural). Miskonsepsi tentang limit bersifat kompleks, universal, dan persisten. Diperlukan pendekatan pengajaran yang secara eksplisit dirancang untuk mengkonfrontasi miskonsepsi ini, seperti penggunaan multipresentasi dan assessment diagnostik. Penelitian lebih lanjut sangat diperlukan, khususnya dalam konteks Indonesia, untuk mengembangkan dan menguji efektivitas strategi intervensi yang spesifik.

Kata Kunci: Systematic Literature Review; Miskonsepsi; Kesulitan; Konsep Limit; Kalkulus; Mahasiswa; Pendidikan Matematika.

ABSTRACT

The concept of the limit serves as a critical foundation for calculus and mathematical analysis, while also representing a significant transitional point towards abstract and formal mathematical thinking. However, students globally encounter substantial and recurrent difficulties in grasping the essence of this concept. This systematic literature review aims to synthesize empirical evidence to identify the types, patterns, and causal factors of misconceptions and difficulties experienced by students in understanding the concept of limits. A systematic search was conducted across the Scopus, Web of Science, ERIC, and Google Scholar databases for empirical studies published between 2001 and 2024. The selection and data extraction process followed the PRISMA protocol. Data from the included studies were analyzed using thematic analysis, resulting in the inclusion of 30 studies that met the eligibility criteria. A synthesis of the 30 studies reveals persistent patterns of misconception, particularly the understanding of a limit as an unfinished dynamic process, the conflation of a limit with a function's value, and profound difficulties with multiple representations and the formal epsilon-delta definition. The causal factors are multidimensional, encompassing cognitive aspects (everyday intuition, weak prerequisite knowledge), epistemological aspects (instrumentalist beliefs about mathematics), and pedagogical aspects (overly procedural teaching). Misconceptions regarding limits are complex, universal, and persistent. Teaching approaches explicitly designed to confront these misconceptions are required, such as the use of multiple representations and diagnostic assessments. Further research is urgently needed, particularly within the Indonesian context, to develop and test the effectiveness of specific intervention strategies.

Keywords: Systematic Literature Review; Misconceptions; Difficulties; Limit Concept; Calculus; University Students; Mathematics Education.

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1. INTRODUCTION

The concept of the limit (Laja, 2022) is a fundamental and inseparable foundation of calculus and mathematical analysis. As emphasized by Stewart (2021), a deep understanding of limits is an absolute prerequisite for defining two other key concepts: derivatives and integrals. More than just a topic in the syllabus, the limit marks a critical transitional point in students' cognitive journey, from procedural and computational mathematical thinking towards the abstract, formal, and deductive thinking characteristic of advanced mathematics (Tall, 1992; Junaeti et al., 2023).

However, this transition is often not smooth. Empirical evidence from various parts of the world consistently shows that students face significant and recurring difficulties in grasping the essence of limits. Previous studies, such as those by Bezuidenhout (2001) and Fern á ndez-Plaza & Simpson (2016), reveal that misconceptions about limits are not an isolated phenomenon but rather a persistent and complex problem. Students often become trapped in a narrow understanding, viewing the limit merely as an algorithmic procedure of "approaching" without appreciating its formal meaning as a unique number that can be rigorously defined (Oehrtman et al., 2008; Prihandhika & Azizah, 2025). This difficulty peaks when students are introduced to the formal epsilon-delta definition, which many consider the most challenging topic in the entire calculus curriculum (Roh, 2008; Ningsih & Deswita, 2023).

Although numerous empirical studies have investigated various dimensions of student misconceptions and difficulties (Salamah, Susiaty, & Ardiawan, 2022; Sadiah & Afriansyah, 2023) with the concept of the limit, the resulting knowledge remains scattered and fragmented. Each study tends to focus on specific contexts, samples, and particular aspects of this issue. Therefore, there is an urgent need for a comprehensive and systematic synthesis to consolidate findings from these diverse studies. A systematic literature review (SLR) is necessary to map the landscape of existing evidence, identify common patterns and consistencies across studies, and reveal knowledge gaps that future research needs to address (Tareq & Rahmah, 2024; Afriansyah & Sugiarti, 2025). Without a comprehensive synthesis, it is impossible to distinguish between context-specific findings and the universal patterns underlying limit misconceptions. This fragmentation, in turn, hinders the development of effective and generalizable pedagogical strategies. Therefore, the novelty of this systematic review lies in its endeavor to consolidate these scattered findings to identify consistent patterns of misconceptions across contexts, reveal the interplay of cognitive, epistemological, and pedagogical factors as root causes, and provide a robust evidence base for recommendations for teaching practice and future research agendas.

Based on the background and problem formulation above, this systematic literature review aims to answer the following research questions:

a. What are the most common types of misconceptions and difficulties experienced by students in understanding the concept of limits?
b. What factors are identified as the causes of these misconceptions and difficulties?
c. What are the implications of the findings in the literature for future teaching practices and research?

2. METHOD

This research constitutes a Systematic Literature Review (SLR). An SLR is conducted to identify, evaluate, and interpret all available research findings relevant to a specific research question, topic area, or phenomenon of interest (Kitchenham & Charters, 2007). This method was selected for its capacity to provide a comprehensive, objective, and replicable synthesis of evidence while minimizing bias through the use of a clear, documented protocol. The reporting of this review adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021) to ensure transparency and completeness.

The search strategy was designed to identify all potentially relevant literature.

a. The final literature search was conducted on Juli, 2025.
b. Data Sources (Electronic Databases): The literature search was conducted systematically across the following four indexed academic databases:
   1) Scopus (www.scopus.com)
   2) Web of Science Core Collection (www.webofscience.com)
   3) ERIC (Education Resources Information Center) (eric.ed.gov)
   4) Google Scholar (scholar.google.com) – Searches in Google Scholar were limited to the first 200 most relevant results for each main keyword combination to manage the large volume of returns (Haddaway et al., 2015).

Keywords and Search Strategy: Keyword combinations were developed based on the research questions and underwent preliminary testing. Boolean operators (AND, OR) were used to optimize the search. The search syntax used for databases such as Scopus and Web of Science was as follows: (`"student difficult*"` OR `misconception*` OR `"alternative conception"` OR `"conceptual understanding"`) AND (`limit*` OR `calculus`) AND (`"university student*"` OR `undergraduate*` OR `"tertiary education"` OR `"higher education"`).

a. Inclusion Criteria:
   1) Empirical studies (qualitative, quantitative, or mixed-methods) presenting primary data on student misconceptions or difficulties.
   2) Research participants were undergraduate students in higher education institutions.
   3) The primary focus of the research is the conceptual understanding of function limits in calculus.
   4) Articles published in peer-reviewed journals or peer-reviewed conference proceedings.
   5) Published within the time range of 2001 – 2024 to ensure relevance to the contemporary educational context.
   6) The full text is available and accessible.
b. Exclusion Criteria:
   1) Review articles, conceptual articles, books, or book chapters without new empirical data.
   2) Studies focusing on secondary school students.
   3) Studies that only discuss the development of learning media/tools without an in-depth analysis of misconceptions.
   4) Articles written in languages other than Indonesian or English.

The article selection process was conducted in stages by two researchers independently to reduce bias. Any discrepancies were resolved through discussion or by consulting a third researcher if necessary.

a. Identification: Search results from all databases were collated and merged using reference management software (Mendeley/Zotero). Duplicates were removed both automatically and manually.
b. Screening: Based on title and abstract, articles were screened for initial eligibility according to the inclusion and exclusion criteria.
c. Eligibility: The full texts of articles that passed the initial screening were thoroughly examined to determine final eligibility.
d. Included: Articles meeting all criteria were finally included in the review process.
e. This entire process was documented using a PRISMA Flow Diagram to provide a clear and transparent overview of the number of articles identified, screened, and included, along with the reasons for exclusion.

Data from each eligible study were extracted into a standardized table. The extracted data included:

a. Bibliometric Information: Author(s), Year of Publication, Title, Source.
b. Methodology: Research design, Context/Location, Number and characteristics of participants, Data collection instruments (tests, interviews, questionnaires).

c. Key Findings: Types of misconceptions identified, reported contributing factors, and suggested implications.

Data analysis was performed using thematic analysis (Braun & Clarke, 2006). This process was conducted iteratively through several stages: (1) familiarization with the data by reading and extracting key findings from each study; (2) generating initial codes to categorize types of misconceptions and causal factors; (3) searching for themes by grouping similar codes into coherent themes; (4) reviewing and refining themes to ensure they accurately represented the collated data; and (5) defining and naming the final themes, which are presented to address the research questions. This process involved identifying consistent patterns across the literature, as well as noting any notable inconsistencies or contradictions.

3. RESULT AND DISCUSSION

a. Study Selection Process

The study selection process, detailed in the PRISMA flow diagram (Figure 1), began with the identification of 614 records from electronic databases. No additional records were identified through other sources. After the removal of 132 duplicate records and 10 records removed for other reasons, a total of 472 records underwent the title and abstract screening phase. During this screening, 360 records were excluded as they did not meet the eligibility criteria. The full texts of the remaining 112 reports were sought for retrieval. Of these, 6 reports could not be retrieved, leaving 106 reports to be assessed for eligibility through full-text review. Following a thorough evaluation, 76 reports were excluded for not meeting the inclusion criteria. Ultimately, 30 studies were deemed eligible and included in the qualitative synthesis of this systematic review.

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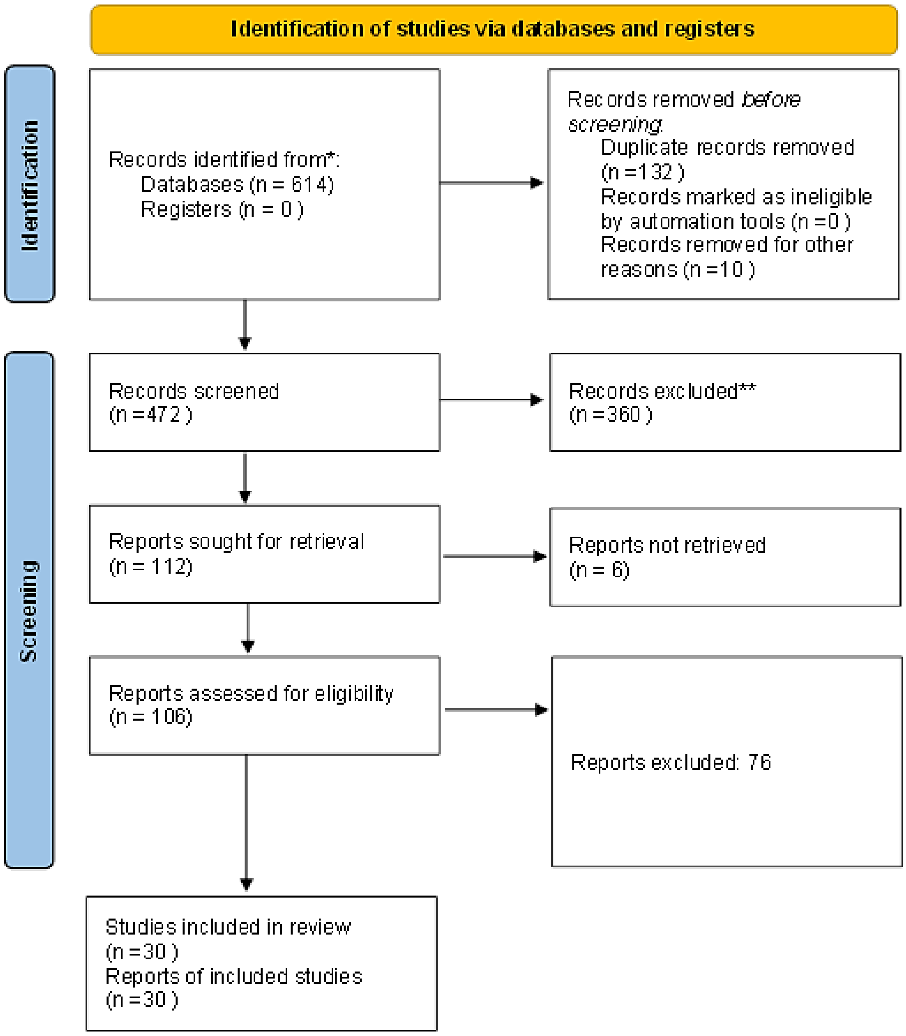

Figure 1. PRISMA Flow Diagram of the Study Selection Process

b. Characteristics of Included Studies

Based on the selection process following the PRISMA protocol, a total of 30 empirical studies met all eligibility criteria and were included in this systematic review. These studies were published between 2001 and 2024. The majority of the research employed qualitative (n=17) or mixed-methods (n=9) approaches, emphasizing in-depth conceptual understanding, while a smaller number of studies were quantitative in nature (n=4). The studies were conducted across diverse geographical contexts, with a primary distribution from the United States (n=11), Turkey (n=5), Indonesia (n=4), and several other European and Asian countries (n=1).

Table 1. Summary of the Characteristics of the Included Studies

Author(s) (Year)	Location	Method	Participants	Instruments	Key Findings Related to Limits
Bezuidenhout (2001)	South Africa	Qualitative	174 students	Interviews, tests	Students tended to evaluate limits by direct substitution and

Author(s) (Year)	Location	Method	Participants	Instruments	Key Findings Related to Limits
					disregarded the function's behavior around the point.
Roh (2008)	Korea	Qualitative	6 students	Task-based interviews	Images of sequences "fading away" reinforced misconceptions about convergence.
Fernández-Plaza & Simpson (2016)	Spain	Mixed-Methods	28 students	Tests, interviews	Identified three distinct understandings of limits: dynamic, approximation, and formal.
Ubuz & Erbaş (2005)	Turkey	Qualitative	35 students	Clinical interviews	Difficulties in linking graphical representations with the formal limit concept.
Prasetyo et al. (2021)	Indonesia	Mixed-Methods	127 students	Two-tier tests, interviews	68.5% of students held misconceptions in determining trigonometric function limits.
Oehrtman (2009)	USA	Quantitative	120 students	Open-ended questionnaires	The "processes that never finish" metaphor was a primary obstacle to understanding.
Tall & Vinner (1981)	UK	Conceptual	-	-	Introduced the "Concept Image" vs. "Concept Definition" theory as a theoretical basis.
Swinyella et al. (2023)	Indonesia	Qualitative	30 students	Tests, interviews	Misconceptions were caused by an inability to connect symbolic and visual representations.
Adiredja, A. P., & James, K. (2021)	United States (University of Arizona)	Qualitative – Knowledge in Pieces framework; in-depth interview analysis	Undergraduate calculus students	Clinical interviews, $\varepsilon - \delta$ problem-based tasks	Students struggled to understand the logical structure and temporal order of the $\varepsilon - \delta$ definition ("for every $\varepsilon > 0$, there exists $\delta > 0$…"). Many reversed the $\varepsilon - \delta$ dependency, misinterpreted quantifiers, and experienced conflict between intuitive and formal notions of limits.
Viirman, O., Vivier, L. & Monaghan, J. (2022)	Three countries (varies by study context; typically Europe &	Comparative study – task analysis and conceptual evaluation	High-school students, university students, and pre-service teachers	Task analysis, concept tests, limited interviews	Students had significant difficulty applying the formal definition of limits, particularly with tasks requiring "given ε, find δ." Many were able to compute limits but did not understand the formal $\varepsilon - \delta$ structure. The definition was

Author(s) (Year)	Location	Method	Participants	Instruments	Key Findings Related to Limits
	Latin America)	across levels			rarely used, resulting in weak ability to construct δ based on ε .

c. Findings for Research Question 1: Types of Misconceptions and Difficulties

A synthesis of the 30 studies revealed several of the most common and persistent types of misconceptions and difficulties:

Theme 1: Misconceptions about the Nature and Ontological Status of the Limit

1) Limit as an Unfinished Dynamic Process: Students view the limit as a process of "approaching" or "moving towards" a value that is never actually attained (Oehrtman, 2009). This process-oriented view impedes the understanding that a limit is a number (a static object). This conception was reported in the majority of studies (noted in 20 of the 30 studies) that addressed it, making it one of the most common and persistent hurdles.
2) Equating the Limit and the Function's Value: The belief that if a function f is defined at x = c,, then lim lim (x→c) f(x) = f(c). Conversely, if f(c) is undefined, students conclude that the limit does not exist (Bezuidenhout, 2001). This type of misconception was identified in 18 studies, often reinforced by students' early experiences with direct substitution.

Theme 2: Difficulties with Multiple Representations

1) Inconsistencies Between Representations: Students often fail to connect information from graphical representations with numerical or symbolic ones. For instance, they are unable to identify the limit from the graph of a function that has a hole at that point (Ubuz & Erbaş, 2005).
2) Over-reliance on Symbolic Representation: Exclusive dependence on algebraic manipulation without graphical or conceptual understanding (Prasetyo et al., 2021).

Theme 3: Profound Difficulties with the Formal Epsilon-Delta Definition

1) Failure to Understand the Order of Quantifiers: Students often reverse the order or perceive the epsilon-delta definition as a "procedure" in which epsilon is chosen after delta (Roh, 2008; Fern á ndez-Plaza & Simpson, 2016).
2) Perceiving the Definition as a Meaningless Object: The formal definition is taught as a series of symbols to be memorized, rather than as a rigorous expression of the idea of "distance" and "approximation" (Swinyella et al., 2023). Nearly all studies (26 of 30) that touched on this topic confirmed that the epsilon-delta definition represents the peak of conceptual difficulty for students.

d. Findings for Research Question 2: Contributing Factors

These misconceptions and difficulties are caused by the interaction of several factors:

1) Cognitive Factors:
   - Intuition and Everyday Experience: Real-world experiences with "approaching" reinforce the incomplete process metaphor (Tall, 1992).
   - Weak Prerequisite Knowledge: Deficiencies in algebra, trigonometry, and the understanding of functions (Prasetyo et al., 2021).

2) Epistemological Factors:

   Instrumentalist Beliefs: The belief that mathematics is about memorizing and applying formulas (Tall & Vinner, 1981).

3) Pedagogical Factors:

   Overly Procedural Teaching: A rushed curriculum focused on computational exercises (Ubuz & Erbaş, 2005).

e. Findings for Research Question 3: Implications for Pedagogy and Assessment

The literature synthesis not only identified problems but also yielded a number of recommendations proposed by researchers to address misconceptions and difficulties in understanding limits. These implications can be grouped into two main areas: pedagogy and assessment.

1) Pedagogical Implications

   Based on the findings from various studies, the literature consistently recommends a shift from procedural teaching towards a more conceptual and reflective approach.
   - Multiple Representations Approach: Instruction should deliberately and explicitly connect various representations of the limit concept: symbolic, numerical (tables of values), graphical, and verbal. Studies by Ubuz & Erbaş (2005) and Zandieh (2000) emphasize that students' main difficulties often lie in their inability to translate between these representations.
   - Instruction that Explicitly Confronts Misconceptions: Rather than avoiding errors, instruction should incorporate common misconceptions as part of the learning process. This technique is often referred to as *cognitive conflict* or using *negative examples*.
   - Delaying and Preparing for the Introduction of the Formal (Epsilon-Delta) Definition: Most of the literature (e.g., Tall, 1992; Roh, 2008) advises against hastily introducing the epsilon-delta definition. Instead, instructors should first build a strong intuitive foundation.

2) Implications for Assessment

The literature also highlights the need to reform assessment methods to align with the goals of conceptual learning.

- Use of Diagnostic Assessment: It is crucial to identify misconceptions early, before they become entrenched. Diagnostic tests, particularly two-tier tests, have proven effective for this purpose (Prasetyo et al., 2021; Swinyella et al., 2023). The first-tier tests content knowledge (the answer), while the second tier tests the reasoning behind that answer.
- Diversification of Assessment Instruments: Assessment should not consist solely of procedural problems. Assessment instruments should include tasks that demand conceptual understanding, reasoning, and communication.

f. Discussion

This systematic review successfully consolidates evidence from 30 empirical studies, demonstrating that misconceptions about limits are not random occurrences but rather persistent and predictable patterns. The existence of consistent misconceptions across diverse cultures and educational contexts, as identified in the United States (Oehrtman, 2009), Korea (Roh, 2008), Turkey (Ubuz & Erbaş, 2005), and Indonesia (Prasetyo et al., 2021; Swinyella et al., 2023), indicates that the root of the problem may lie in how humans process abstract concepts and their prior mathematics learning experiences.

First, misconceptions often originate from robust intuitions and everyday experiences. The metaphors of "approaching" or an "unending process" proposed by Oehrtman (2009) are highly intuitive; they align with our physical experience of moving towards an object. Unfortunately, this real-world intuition clashes with the static, precise mathematical definition of a limit as a number. Second, prior mathematics learning experiences in secondary education often emphasize procedural calculations and direct substitution, thereby reinforcing the misconception that lim (x→c) f(x) is always equal to f(c) (Bezuidenhout, 2001). When students encounter the rigorous epsilon-delta definition, they experience what Tall (1992) termed "cognitive shock," as their previous way of thinking becomes inadequate.

The findings of this review find a powerful explanatory framework in two major theories:

1) Concept Image and Concept Definition (Tall & Vinner, 1981): This theory distinguishes between the *concept definition* (the formal, taught definition) and the *concept image* (the mental network containing all pictures, properties, and experiences associated with the concept). Conflict arises when a student's concept image (e.g., "a limit is an approach") is not aligned with the formal concept definition (e.g., the epsilon-delta definition). This review shows that the identified misconceptions, such as viewing a limit as a dynamic process, are manifestations of a dominant yet inaccurate concept image.

2) APOS Theory (Action, Process, Object, Schema): This theory explains the development of mathematical understanding from an *action*, to a *process*, which is then encapsulated into an *object*, and finally connected into a *schema*. The review's findings indicate that many students remain stuck at the *process* level—they view the limit as a procedure of "approaching" that must be performed—and fail to encapsulate it into an *object* (a value) that can be manipulated in further operations (for instance, within the definitions of continuity or the derivative). Difficulties with the epsilon-delta definition demonstrate the need for students to coordinate various *processes* and *objects* into a coherent *schema*, which represents a significant cognitive challenge.
3) Collectively, the findings synthesized in this review not only reinforce the explanatory power of Concept Image and APOS Theory but also squarely challenge the adequacy of traditional, procedural approaches to teaching calculus. The consistency of the observed misconceptions demands a refinement in how these theories are applied in the classroom. The implication is a necessary shift from merely explaining formal definitions towards instructional designs that deliberately target and reconstruct flawed concept images, and that facilitate the encapsulation of processes into objects through more meaningful learning experiences.

Several limitations inherent in this SLR process must be acknowledged to provide appropriate context for the presented findings:

1) Language Bias: The inclusion criteria, limited to Indonesian and English articles, potentially overlook significant findings published in other languages. This may affect the generalizability of the findings.
2) Methodological Quality of Primary Studies: The quality of this synthesis is highly dependent on the quality of the included studies. There was variation in methodological rigor across studies, particularly concerning the description of instruments, data analysis procedures, and their validity. Qualitative studies may contain subjective interpretations, while some quantitative studies may have employed inadequately validated instruments.
3) Scope Limitation: This review focused specifically on the concept of the limit of a function. Although the limit is a foundational concept, misconceptions in closely related topics such as continuity, derivatives, and integrals were not discussed, despite their strong interconnections.

4. CONCLUSION

The primary contribution of this systematic review is to provide a comprehensive and up-to-date mapping of empirical evidence from over two decades on limit misconceptions. This review has successfully identified and consolidated persistent, universal patterns and revealed the interplay of cognitive, epistemological, and pedagogical factors as the root of the problem. The main findings reveal that misconceptions about limits such as viewing them as an unfinished dynamic process, equating them with the function's value, and profound difficulties with multiple representations and the formal epsilon-delta definition—are a complex, universal, and persistent phenomenon. This persistence is driven by a multifaceted interaction of causal factors.

Based on these findings, specific and actionable suggestions are proposed. First, for educators, teaching approaches must shift from procedural to conceptual, explicitly leveraging multiple representations (symbolic, numeric, graphic) to build bridges of understanding. Second, instruction should be designed to induce cognitive conflict by presenting examples and non-examples that directly challenge common misconceptions, such as functions with a limit at a point where the function is undefined. Third, diagnostic assessments, like two-tier tests, need to be routinely implemented to identify conceptual gaps early before these misconceptions become entrenched. For researchers, further studies are urgently needed to test the effectiveness of the aforementioned interventions, particularly within the Indonesian context, and to develop more validated diagnostic instruments.

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