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HEURISTIC PROCESSES AND THE DEVELOPMENT OF METACOGNITION IN MATHEMATICS TEACHING AND LEARNING

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ABSTRACT

Objectives: This study aims to explore the conceptual and procedural elements of using heuristics in the teaching of Experimental Sciences and their impact on strengthening students' cognitive and metacognitive competencies. Heuristic strategies such as analogy, working backward, and problem segmentation are analyzed to determine their role in metacognitive development.

Theoretical Framework: The theoretical framework emphasizes heuristics as a set of methods and strategies that foster discovery and problem-solving. These tools are essential for promoting active and reflective learning, as well as addressing current academic and professional challenges.

Methodology: This study adopts a qualitative-descriptive approach based on action research. Heuristic strategies applied in educational contexts were analyzed through interviews with students and teachers, along with systematic classroom observations.

Results and Discussion: The findings reveal that integrating heuristic processes into teaching enhances the understanding of complex concepts, fosters autonomous learning, and promotes critical reflection among students. Additionally, teacher training in these strategies is identified as crucial to maximizing their effectiveness in educational settings.

Research Implications: This study highlights the importance of incorporating heuristic strategies into educational programs to strengthen students' metacognitive competencies and improve reflective learning. Future research should explore the adaptability of these strategies across different cultural and educational contexts.

Originality/Value: This work stands out for its detailed analysis of heuristics as a key tool in developing metacognitive competencies. It provides empirical evidence supporting the relevance of these strategies for education in Experimental Sciences and offers a conceptual foundation for future research.

Keywords: Reflective Competencies, Autonomous Learning, Problem-Solving, Analogy and Segmentation, Conceptual Development.

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PROCESSOS HEURÍSTICOS E O DESENVOLVIMENTO DA METACOGNIÇÃO NO ENSINO E APRENDIZAGEM DA MATEMÁTICA

RESUMO

Objetivos: Este estudo tem como objetivo explorar os elementos conceituais e procedimentais do uso da heurística no ensino de Ciências Experimentais e seu impacto no fortalecimento das competências cognitivas e metacognitivas dos estudantes. Estratégias heurísticas como analogia, raciocínio reverso e segmentação de problemas são analisadas para determinar seu papel no desenvolvimento metacognitivo.

Referencial Teórico: O referencial teórico destaca a heurística como um conjunto de métodos e estratégias que estimulam a descoberta e a resolução de problemas. Essas ferramentas são essenciais para promover um aprendizado ativo e reflexivo, além de enfrentar os desafios acadêmicos e profissionais atuais.

Metodologia: Este estudo adota uma abordagem qualitativa-descritiva baseada na pesquisa-ação. Foram analisadas estratégias heurísticas aplicadas em contextos educacionais por meio de entrevistas com estudantes e professores, além de observações sistemáticas em sala de aula.

Resultados e Discussão: Os resultados mostram que a integração de processos heurísticos no ensino melhora a compreensão de conceitos complexos, promove a aprendizagem autônoma e incentiva a reflexão crítica entre os estudantes. Além disso, identificou-se que a formação de professores nessas estratégias é fundamental para potencializar sua eficácia no âmbito educacional.

Implicações da Pesquisa: Este estudo ressalta a importância de incorporar estratégias heurísticas nos programas educacionais para fortalecer as competências metacognitivas dos estudantes e aprimorar o aprendizado reflexivo. Sugere-se explorar a adaptabilidade dessas estratégias em diferentes contextos culturais e educacionais.

Originalidade/Valor: Este trabalho se destaca por sua análise detalhada da heurística como uma ferramenta-chave no desenvolvimento de competências metacognitivas. Oferece evidências empíricas que apoiam a relevância dessas estratégias para a educação em Ciências Experimentais e fornece uma base conceitual para pesquisas futuras.

Palavras-chave: Competências Reflexivas, Aprendizagem Autônoma, Resolução de Problemas, Analogias e Segmentação, Desenvolvimento Conceitual.

LOS PROCESOS HEURÍSTICOS Y EL DESARROLLO DE LA METACOGNICIÓN EN LA ENSEÑANZA APRENDIZAJE DE LA MATEMÁTICA

RESUMEN

Objetivos: El objetivo de este estudio es explorar los elementos conceptuales y procedimentales del uso de la heurística en la enseñanza de las Ciencias Experimentales y su impacto en el fortalecimiento de competencias cognitivas y metacognitivas en estudiantes. Se analizan estrategias heurísticas como la analogía, el trabajo hacia atrás y la segmentación de problemas para determinar su papel en el desarrollo metacognitivo.

Marco Teórico: El marco teórico subraya la heurística como un conjunto de métodos y estrategias que estimulan el descubrimiento y la resolución de problemas. Estas herramientas son esenciales para promover un aprendizaje activo y reflexivo, así como para enfrentar los desafíos académicos y profesionales actuales.

Metodología: Este estudio adopta un enfoque cualitativo-descriptivo basado en la investigación-acción. Se analizaron estrategias heurísticas aplicadas en contextos educativos mediante entrevistas a estudiantes y docentes, además de observaciones sistemáticas en el aula.

Resultados y Discusión: Los resultados muestran que la integración de procesos heurísticos en la enseñanza mejora la comprensión de conceptos complejos, fomenta el aprendizaje autónomo y promueve la reflexión crítica entre los estudiantes. Además, se identificó que la formación docente en estas estrategias es clave para potenciar su efectividad en el ámbito educativo.

Implicaciones de la Investigación: Este estudio resalta la importancia de incorporar estrategias heurísticas en los programas educativos para fortalecer las competencias metacognitivas de los estudiantes y mejorar el aprendizaje reflexivo. Se sugiere explorar la adaptabilidad de estas estrategias en diferentes contextos culturales y educativos.

Originalidad/Valor: El trabajo destaca por su análisis detallado de la heurística como una herramienta clave en la formación de competencias metacognitivas. Ofrece evidencia empírica que respalda la relevancia de estas estrategias para la educación en Ciencias Experimentales y proporciona una base conceptual para futuras investigaciones.

Palabras clave: Competencias Reflexivas, Aprendizaje Autónomo, Resolución de Problemas, Analogía y Segmentación, Desarrollo Conceptual.

1 INTRODUCTION

In the teaching of Experimental Sciences, it is essential to promote cognitive and metacognitive skills that prepare students to face academic challenges. in the 21st century . Heuristics, understood as a set of strategies and methods to foster discovery and problem solving, has been highlighted as a powerful tool in this context (Row & Sathasivam, 2022). These strategies facilitate active learning, and also promote a reflective and critical approach in students, which is essential for the development of autonomous and effective thinking skills.

Mathematics teaching benefits significantly from the integration of heuristic processes. Students' ability to connect abstract concepts to concrete experiences through analogies or to approach complex problems by breaking them down into more manageable parts is key to their academic success ((Nokhatbayeva, 2020)). However, despite the recognized importance of these processes, there is still a gap in understanding how heuristic elements specifically impact the development of metacognitive competencies in mathematics teaching.

The general objective of this research is to explore the conceptual and procedural elements of the use of heuristics in the teaching of Experimental Sciences, with a particular focus on mathematics, and to understand its impact on the acquisition of cognitive and metacognitive skills in students of the Experimental Sciences Education degree. Through a qualitative-descriptive approach, following the action-research methodology proposed by , the heuristic strategies used in Kemmis et al. (2014)the classroom were analyzed , and the perceptions of both students and teachers about their effectiveness were systematized.

This study aims not only to enrich the current literature on heuristics and education, but also to provide practical suggestions that contribute to continuous improvement in mathematics teaching. By deepening the understanding of how heuristic processes impact metacognitive development, it becomes possible to design more effective educational interventions, aimed at preparing students to successfully face both academic and professional challenges.

Research Question: How do heuristic elements in the teaching of experimental sciences contribute to the development of cognitive and metacognitive skills in students of the Experimental Sciences Education program?

1.1 SPECIFIC OBJECTIVES

To refer to the relationship between heuristic elements and problem solving in Experimental Sciences, based on the analysis of the literature and the concepts studied.

Describe the principles and heuristic strategies applied in the teaching-learning of Experimental Sciences in the degree of Education in Experimental Sciences.

Analyze the heuristic procedures used in problem solving, within the context of Experimental Sciences, highlighting their relevance for the development of cognitive and metacognitive skills.

To systematize existing theories and methodologies on the use of heuristics in the teaching of Experimental Sciences, in order to establish a solid conceptual basis for future research.

2 THEORETICAL FRAMEWORK

2.1 INTRODUCTION TO HEURISTICS IN TEACHING EXPERIMENTAL SCIENCES

Heuristics comprises strategies that facilitate the discovery and resolution of problems, being essential in the teaching of Experimental Sciences. This approach encourages active learning, where students develop skills to address complex problems, overcoming purely algorithmic methods. Its relevance lies in promoting active participation, transforming students into protagonists of their own learning, beyond memorization (Row & Sathasivam , 2022).

In the teaching of Experimental Sciences, heuristics guide learning based on exploration, inquiry, and problem solving. This approach promotes deep understanding by allowing students to apply knowledge in new and challenging contexts. It also encourages critical thinking and effective problem solving, essential skills in the scientific field. (Nokhatbayeva, 2020).

2.2 HEURISTIC PRINCIPLES AND STRATEGIES

Heuristic principles, such as analogies and reduction techniques, are essential to guide students towards innovative solutions to complex problems. Analogies allow connecting prior knowledge to new challenges, facilitating understanding and encouraging lateral thinking when approaching problems from different perspectives. This approach is key in science, where solving complex problems requires creativity and innovation (Nokhatbayeva , 2020).

Reduction, on the other hand, involves breaking down a problem into more manageable parts or simplifying it to a previously solved form. This approach is particularly useful in situations where problems are so complex that tackling them in their entirety would be overwhelming for students. By reducing a problem to simpler components, students can tackle each part sequentially, making it easier to understand and solve the problem as a whole.(Yan et al., 2024).

Heuristic strategies, such as working forward and working backward, are crucial in problem solving. Working forward starts with the available data and moves step by step toward the solution, being useful when the path is unclear. Working backward, on the other hand, starts from the desired solution and works backward to identify the necessary steps, being effective in problems that require detailed planning and organization.(Yan et al., 2024)

Heuristics are not limited to solving mathematical or scientific problems, but are also key in teaching metacognitive skills. These skills allow students to reflect on their thinking processes, monitor their progress, and adjust their strategies when necessary. In this way, heuristics not only facilitate problem solving but also contribute to the development of long-lasting learning skills essential for academic and professional success (Row & Sathasivam , 2022).

2.3 APPLICATION OF HEURISTICS IN EDUCATION IN EXPERIMENTAL SCIENCES

In the context of the Experimental Science Education program, the use of heuristics has proven to be an effective tool to optimize the teaching-learning process. Studies indicate that heuristic strategies not only enhance students' academic performance, but also foster cognitive and metacognitive skills essential for their future success as science educators (Al- Gaseem et al., 2020).

The use of heuristics not only facilitates the acquisition of knowledge, but also develops practical skills essential for students' future careers as educators. By promoting an active and participatory approach, students directly experiment with scientific concepts, applying them in real-life situations and solving problems that reflect classroom challenges. This approach improves their understanding of the concepts and provides them with tools to effectively teach their future students.(Tsankov, 2022).

Heuristics also promote the integration of new knowledge with existing knowledge, establishing a solid foundation that allows students to expand their understanding towards more advanced concepts. This integrative approach is especially effective in teaching experimental sciences, where concepts build on prior knowledge, and a deep understanding of the fundamentals is crucial to successfully progress to higher levels (Tsankov , 2022).

A key aspect of heuristics is their ability to foster both teamwork and cognitive autonomy. By solving problems that require collaboration and the exchange of ideas, students develop communication and cooperation skills, essential in the professional field. At the same time, it promotes cognitive autonomy, motivating students to take responsibility for their learning, seek solutions independently, and trust in their ability to solve complex problems (Nokhatbayeva , 2020).

2.4 HEURISTICS AS A PEDAGOGICAL APPROACH

The heuristic-based pedagogical approach develops critical thinking and encourages autonomous and reflective learning. It is crucial in teacher training, as future educators must master content and teach their students to solve problems independently. This ability is key in today's education, which not only transmits knowledge but also prepares students to face real-world challenges (Oktaviana et al., 2023).

In this sense, heuristics not only facilitate the acquisition of knowledge, but also contribute to the development of a critical and proactive attitude towards learning. By encouraging an approach in which students question, investigate and discover for themselves, heuristics promotes a deeper and more lasting understanding of scientific concepts. This approach also prepares students to be lifelong learners, capable of adapting to new challenges and of continuing to learn and grow throughout their professional careers.(Hand et al., 2021)

The use of heuristics as a pedagogical approach has proven to be effective in increasing student motivation and engagement. By actively involving students in their own learning process and making it an interactive and participatory experience, heuristics contribute to increasing interest and motivation. This not only elevates their academic performance but also enriches the learning experience, making it more satisfying and rewarding (Oktaviana et al., 2023).

2.5 IMPACT OF HEURISTICS ON THE DEVELOPMENT OF METACOGNITIVE COMPETENCES

The use of heuristics in the teaching of experimental sciences promotes metacognitive skills, helping students reflect on their learning, identify strengths and weaknesses, and adjust strategies to improve. Metacognition is key in learning, as it allows not only understanding the content, but also recognizing how it is learned. This forms more autonomous and effective students, capable of optimizing their performance (Fleur et al., 2021).

In the teaching of Experimental Sciences, metacognition is key for students to plan, monitor, and evaluate their actions when solving complex problems. Heuristics foster these skills, preparing students to face academic challenges and adapt to professional and personal situations. Critically reflecting on their learning and adjusting strategies is essential in any field, and heuristics offer tools to develop this ability (Rusyati et al., 2021).

Furthermore, the impact of heuristics on the development of metacognitive skills goes beyond the classroom. Students who acquire these skills through heuristics are better prepared to face the challenges of the 21st century, as they can apply what they have learned in new situations and solve problems autonomously. The ability to transfer skills and knowledge to different contexts is a key characteristic of effective and lasting learning (Rusyati et al., 2021).

2.6 HEURISTIC THEORIES IN TEACHING

2.6.1 Pólya's Problem Solving Theory

George Pólya's Problem Solving Theory proposes a four-phase process: understanding the problem, making a plan, executing it, and revising the solution. He stresses the importance of metacognitive reflection, encouraging students to evaluate and adjust their methods based on previous experiences. This approach remains relevant in mathematics education today, promoting autonomous and critical learning (Ambrus & Barczi-Veres, 2022; Schoenfeld, 2010; Sercenia & Prudente, 2023).

2.6.2 Theory of constructivism (Piaget and Vygotsky)

The theory of constructivism, developed by Piaget and Vygotsky, maintains that knowledge is actively constructed through interaction with the environment. Piaget focuses on the processes of assimilation and accommodation at various stages, while Vygotsky highlights the importance of the social context and the Zone of Proximal Development (ZPD), where learning is strengthened through interaction. Both approaches emphasize that learning is a dynamic and contextual process, influenced by social experiences and interactions (Perkowska-Klejman & Górka-Strzałkowska, 2023; Zaretsky, 2021)

2.6.3 Vygotsky's Zone of Proximal Development (ZPD) theory

Vygotsky's Zone of Proximal Development (ZPD) describes the gap between what a person is capable of doing on their own and what they can accomplish with the guidance of a more expert mentor or peer. According to this theory, learning is most effective within this zone, as external support drives progress toward more advanced skills. The ZPD emphasizes the value of social interaction and collaboration for the development of knowledge, favoring guided, gradual learning that drives cognitive growth (Margolis, 2020).

2.6.4 Theory of Multiple Intelligences (Gardner)

The Theory of Multiple Intelligences, proposed by Howard Gardner, questions the idea of a single intelligence and proposes that there are various forms, such as linguistic, logical-mathematical, spatial, musical, bodily-kinesthetic, interpersonal, intrapersonal and naturalistic. According to Gardner, each person has a unique combination of these intelligences, which implies that education must be adapted to individual strengths. This theory has promoted flexible educational methodologies that value cognitive diversity in the classroom (Cavas & Cavas, 2020); (Mieles et al., 2021).

2.6.5 Metacognition Theory (Flavell)

John Flavell developed the Metacognition Theory, which focuses on individuals' ability to reflect on and regulate their cognitive processes effectively. According to Flavell, metacognition includes planning, monitoring, and evaluating cognitive strategies for learning or solving problems. This approach allows students to adjust their strategies as needed, improving their ability to learn autonomously and handle complex tasks more effectively ((Drigas & Mitsea, 2020).

2.7 HEURISTIC METHODOLOGIES IN TEACHING

2.7.1 Problem Solving method

Focused on students developing skills to identify, analyze and solve complex problems, this method has become a key tool for active learning and building skills in practical areas. Authors such as Hmelo- Shin (2023)and Susetyarini et al. (2022)underline its impact on improving critical thinking and collaborative problem-solving skills.

2.7.2 Problem-Based Learning (PBL)

In PBL, students are confronted with problems without clear solutions and work collaboratively to solve them, integrating different disciplines. He Mann et al. (2020)highlights the ability of this approach to foster autonomous research and deep learning, especially in fields such as medicine and engineering.

2.7.3 Discovery learning

In this approach, students actively acquire knowledge through exploration and discovery. According to Ozdem-Yilmaz & Bilican (2020)and Ms (2020), this method promotes active knowledge construction and develops research skills, although it requires careful pedagogical design to avoid cognitive overload.

2.7.4 Guided research method

Here, teachers guide students through the process of scientific inquiry, promoting the development of critical research and analytical thinking skills. According to Istiana et al. (2023), guided inquiry facilitates deeper learning by providing structure while allowing student autonomy in their exploration.

2.7.5 Inquiry method

This method encourages students to ask questions, conduct research, and obtain answers through experimentation. The inquiry approach develops critical thinking and fosters deep learning in science and other areas where experimentation is key.(Shanmugavelu et al., 2020)

2.7.6 Collaborative learning

Collaborative learning involves interaction between students to solve common tasks or problems, promoting social and cognitive skills. According to Taggart & Wheeler (2023)the approach, it improves both academic results and the development of interpersonal skills, such as communication and cooperation.

2.7.7 Metacognitive teaching

This approach teaches students to manage their own learning, to plan, monitor and evaluate their cognitive strategies. According to Theobald (2021), metacognitive teaching is particularly useful for improving self-regulation and self-awareness in the learning process, helping students become more efficient learners.

3 METHODOLOGY

3.1 METHODOLOGICAL APPROACH

This study was carried out following a systematic review methodology based on the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to ensure transparency and rigor in the identification and selection of studies (Page et al., 2020). The review focused on analyzing empirical and theoretical research that explores the use of heuristic processes and their influence on the development of metacognitive competencies in mathematics and experimental science education.

3.2 SEARCH STRATEGY AND USE OF BOOLEAN OPERATORS

To identify relevant studies, an exhaustive search was conducted in four databases: SCOPUS, SciELO, Dialnet and Redalyc. A search strategy with Boolean operators was used to refine the results and ensure that the articles were aligned with the research objectives. The search string applied was:

" Heuristic " OR " metacognition " AND " mathematics " AND " education "

The "OR" operator was used to include studies dealing with either the concepts of " heuristic " or " metacognition ", broadening the spectrum of potential articles. In turn, the "AND" operator restricted the results to those studies that were related to " mathematic " and " education ", excluding mathematics research in non-educational contexts. This strategy allowed capturing articles focused on the teaching and learning of mathematics and experimental sciences through heuristic and metacognitive processes.

3.3 INCLUSION AND EXCLUSION CRITERIA

To ensure that the selected studies were relevant and of quality, inclusion and exclusion criteria were established.

Inclusion criteria included:

1. Empirical or theoretical studies on heuristics and metacognition in an educational context.
2. Publications in the last five years, to ensure that the findings are current.
3. Peer-reviewed articles accessible in full text.
4. Applied studies specifically in the context of mathematics education or experimental sciences.

Exclusion criteria included:

- Studies without empirical application of heuristics in Education.
- Articles focused on areas unrelated to mathematics or science education.
- Studies of low methodological quality or with a lack of information in the methods section.
- Publications older than five years.

Selection and Deletion Process for Records

The initial search in the four databases identified a total of 267 records, distributed as follows: SCOPUS (7), SciELO (9), Dialnet (100) and Redalyc (151).

1. Eliminating duplicates and initial records:

- 20 duplicate records between databases were removed.
- An additional 15 articles were flagged as ineligible by automation tools, which excluded articles published outside the five-year range or in languages not supported by the review.
- 5 records were manually deleted due to access restrictions or lack of topical relevance.

After this stage, 227 articles remained for the screening phase.

2. Initial screening:

- A review of the titles and abstracts of these 227 articles was performed, excluding those that did not meet the specific thematic criteria. As a result, 107 articles were discarded, leaving 120 relevant articles for the full-text evaluation phase.

3. Full text eligibility assessment:

- We attempted to retrieve the full text of the 120 selected articles. However, 20 articles could not be retrieved in full and were therefore removed from the review.
- The remaining 100 articles were further assessed for eligibility, applying the inclusion and exclusion criteria mentioned above.

4. Exclusion of studies in the eligibility phase:

During the full-text review, 64 articles were excluded for the following reasons:

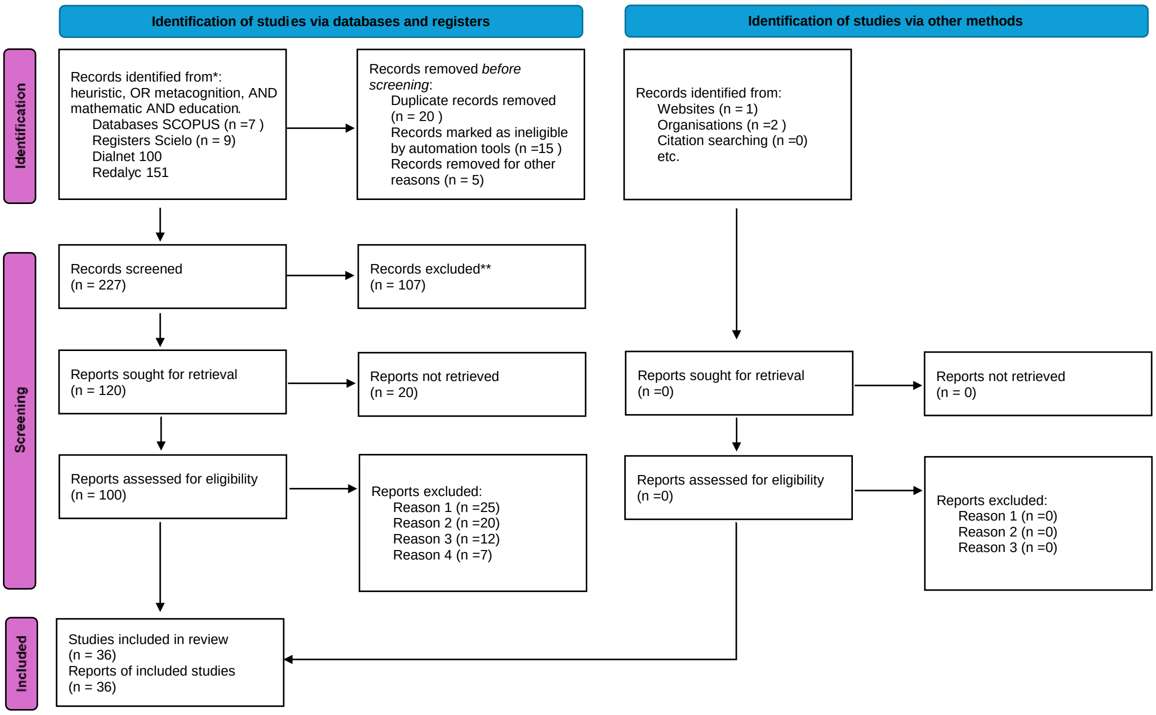
- 25 articles did not empirically apply heuristics in an educational context, but were limited to theoretical aspects without practical application.
- 20 articles focused on areas outside mathematics or science education, such as social sciences or engineering.
- 12 studies had deficiencies in methodological quality or insufficient information in the description of methods.
- Seven articles were excluded because they were outside the time range of the last five years, limiting their relevance to this review.

Articles Included in the Final Review

Finally, 36 articles met all inclusion criteria and were selected for the systematic review. These studies provided significant data on the use of heuristic processes and their impact on the development of metacognitive competencies in students of mathematics and experimental sciences.

Figure 1

Flowchart of the systematic review.



4 RESULTS AND DISCUSSIONS

4.1 RESULTS

4.1.1 Description of included studies

The systematic review included 36 studies that met the established inclusion criteria. These studies cover recent research (last five years) exploring the impact of heuristics and metacognitive strategies on the teaching-learning process in specific educational contexts of mathematics and experimental sciences. The selected studies were published in a variety of peer-reviewed journals, reinforcing the validity and diversity of approaches within the scope of study.

4.1.2 Main findings on the use of heuristics

Heuristics and problem solving: The majority of studies (24 out of 36) highlight the effectiveness of heuristic approaches in teaching mathematical problem solving. Strategies such as analogy, problem decomposition, and working backwards are consistently presented as effective methods for breaking down complex problems into manageable parts, thereby facilitating comprehension and improving performance on advanced mathematical tasks.

Development of metacognitive skills: It is noteworthy that 27 out of 36 studies indicate that heuristic processes not only support the learning of mathematical content, but also promote metacognitive skills. Students who participate in heuristic activities tend to reflect more on their own learning processes, which improves their ability to plan, monitor, and adjust their problem-solving strategies.

Impact on motivation and autonomous learning: A considerable number of studies (18 out of 36) suggest that the implementation of heuristic processes increases students' motivation and encourages autonomous learning. Students involved in the use of heuristic strategies reported feeling more engaged and motivated when actively tackling problems, which facilitates an attitude of continuous learning.

Cultural context and adaptability of heuristic strategies: The reviewed studies indicate a lack of cultural diversity in research on heuristics and metacognition. Furthermore, in cultures where learning traditionally focuses on memorization and reproduction of knowledge, practices that foster reflection and metacognition may not be easily adopted or understood. Most studies come from Western contexts, and only three investigations addressed the applicability of these strategies in non-Western cultural contexts. This gap suggests the need to investigate how heuristic strategies can be adapted to different educational and cultural environments.

4.1.3 Summary of results

The findings suggest that integrating heuristic strategies into the teaching of mathematics and experimental sciences not only strengthens conceptual learning, but also boosts the development of metacognitive skills, promoting deeper and more meaningful learning. Combining heuristic processes with metacognition fosters self-regulation skills and a reflective approach to learning in students.

4.2 DISCUSSION

4.2.1 Impact of heuristic processes on metacognitive development

The results of this review confirm that heuristics are a powerful tool for metacognitive development in students of mathematics and experimental sciences. As suggested by several studies, the use of techniques such as backward working and analogy helps students not only to solve specific problems, but also to reflect on their learning process and to evaluate the effectiveness of the strategies they use ((Nokhatbayeva, 2020); (Row & Sathasivam, 2022)This metacognitive reflection is essential for developing autonomous learning skills, where students learn to evaluate and adjust their methods based on their understanding and progress.

4.2.2 Heuristics and motivation in learning

The review reveals that heuristic strategies also positively influence student motivation. By involving students in their own learning process through activities that require active and reflective participation, heuristic processes stimulate interest and engagement towards learning. This is especially relevant in the field of mathematics education, where motivation and engagement are often determining factors of academic success (Oktaviana et al., 2023). Heuristics seem to create an environment in which students perceive learning as an active and meaningful process, which strengthens their disposition towards autonomous and continuous learning.

4.2.3 Limitations of current research and areas for future research

Despite the observed benefits of using heuristics and metacognition in mathematics education, the review highlights several limitations in the existing literature. First, the majority of the reviewed studies come from Western contexts, limiting the understanding of how these strategies could be applied and adapted in different cultural and educational contexts. It is crucial that future research explores the effectiveness of these strategies in non-Western regions and educational systems to ensure that educational practices are inclusive and globally applicable (Tsankov, 2022).

Furthermore, there is a lack of longitudinal studies assessing the long-term impact of heuristic strategies on metacognitive development and autonomous learning. Most current studies focus on short-term interventions, leaving a gap in understanding how these skills develop and evolve over time. Future research could benefit from exploring the effect of heuristics on sustained metacognitive learning over years, assessing whether these effects endure and how they affect students' academic and professional development (Al-Gaseem et al., 2020).

4.2.4 Contributions and originality of the study

This study contributes to the current literature by offering a detailed and updated synthesis of research on heuristics and metacognition in mathematics education and experimental sciences. The systematic review not only confirms the relevance of these processes in the development of essential academic competences, but also identifies significant gaps in the literature. The originality of the present work lies in its focus on the relationship between heuristic processes and metacognitive competences, emphasizing how the reflective application of these strategies can improve learning and autonomy in students.

4.2.5 Practical implications

The integration of heuristic processes into mathematics and experimental science curricula can have significant benefits. Teachers can use these strategies not only to teach content, but also to foster the development of metacognitive skills that prepare students for continuous and autonomous learning. Furthermore, the study suggests the need for educational systems to adopt a culturally inclusive approach in the implementation of these strategies, ensuring that they are accessible and applicable in diverse educational environments.

5 CONCLUSION

The review demonstrates that heuristic processes, such as analogy and backward working, are effective in improving students' ability to solve complex problems in experimental sciences. The reviewed studies indicate that these strategies allow students to break problems down into manageable parts, facilitating both conceptual understanding and practical application.

The identification of heuristic principles and strategies applied in the educational field shows that these not only help students to confront problems, but also encourage more active and reflective learning. Strategies such as problem decomposition and analogical comparison facilitate deep learning, allowing students to actively engage in their learning process and develop a critical approach. These practices not only improve understanding of the content, but also strengthen metacognitive skills, such as planning and monitoring personal progress.

Heuristic procedures, such as working backwards and using analogies, have been shown to be particularly effective in fostering metacognitive skills such as self-assessment and strategy adjustment. The studies included in the review indicate that students who practice these procedures become more aware of their learning process and are able to adapt their approaches depending on the situation, reflecting significant metacognitive development.

The review has allowed us to systematize current theories and methodological approaches on the use of heuristics in the teaching of Experimental Sciences. This not only provides a robust conceptual framework for future research, but also highlights the importance of heuristics in education as a strategy that facilitates self-assessment and autonomous planning of learning.

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