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A necessary approach to the formation of mathematical concepts

Un acercamiento necesario a la formación de conceptos matemáticos

Uma abordagem necessária para a formação de conceitos matemáticos

Neisy Caridad Rodríguez Morales [1]
https://orcid.org/0000-0002-3623-9051
Andel Pérez González [1]
https://orcid.org/0000-0003-4435-4030
Ortelio Nilo Quero Méndez [1]
https://orcid.org/0000-0002-7872-2957

[1] University of Sancti Spíritus "José Martí Pérez". Cuba
ncrodriguez@uniss.edu.cu ; apgonzalez@uniss.edu.cu ; oquero@uniss.edu.cu

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ABSTRACT
Mathematical knowledge is based on and expanded from the concepts and their relationships with various situations of practical life; hence, the relevance of taking advantage of the potential of its didactic treatment for the integral formation of students from the teaching-learning process of Mathematics. Consequently, the process of concept formation is recognized as a fundamental way for the development of thought and, to its analysis, special importance is given in the Didactics of Mathematics. That is why, this article aims to expose the fundamentals, the didactic regularities and the current demands to be considered during the process of formation of mathematical concepts. For its realization, theoretical and empirical methods were used; of the first, the logical historical, the analytical-synthetic and the inductive-deductive were used in order to make generalizations around the theme. From the latter, the documentary analysis was extracted to interpret the aspirations and methodological requirements of the current governing documents. Its main result is constituted by the theoretical and methodological ideas that were derived from the bibliographic review carried out; the characteristics should guide the process of formation of mathematical concepts in pedagogical practice.

Keywords: concepts; Thought development; concept formation; mathematics and teaching-learning process.

RESUMEN
Los conocimientos matemáticos se fundamentan y amplían a partir de los conceptos y de sus relaciones con diversas situaciones de la vida práctica; de ahí, la pertinencia de aprovechar las potencialidades de su tratamiento didáctico para la formación integral de los estudiantes desde el proceso de enseñanza-aprendizaje de la Matemática. En consecuencia, el proceso de formación de conceptos se reconoce como una vía fundamental para el desarrollo del pensamiento y, a al análisis de este, se le

concede especial importancia en la Didáctica de la Matemática. Es por ello que, este artículo tiene como objetivo exponer los fundamentos, las regularidades didácticas y las exigencias actuales a considerar durante el proceso de formación de conceptos matemáticos. Para su realización se utilizaron métodos teóricos y empíricos; de los primeros se usaron: el histórico-lógico, el analítico-sintético y el inductivo-deductivo, con el fin de hacer generalizaciones en torno a la temática y de los segundos: el análisis documental, para interpretar las aspiraciones y exigencias metodológicas de los documentos rectores vigentes. Su principal resultado lo constituyen las ideas teóricas y metodológicas que se derivaron de la revisión bibliográfica realizada, las cuáles deben guiar el proceso de formación de conceptos matemáticos en la práctica pedagógica.

Palabras clave: conceptos; desarrollo del pensamiento; formación de conceptos; matemática y proceso de enseñanza-aprendizaje.

RESUMO
O conhecimento matemático é baseado e ampliado a partir de conceitos e suas relações com diversas situações da vida prática; daí a relevância de aproveitar o potencial do seu tratamento didático para a formação integral dos alunos a partir do processo de ensino-aprendizagem da Matemática. Consequentemente, o processo de formação de conceitos é reconhecido como um caminho fundamental para o desenvolvimento do pensamento e, a sua análise, ganha especial importância na Didática da Matemática. É por isso que este artigo tem como objetivo expor os fundamentos, regularidades didáticas e demandas atuais a serem consideradas durante o processo de formação de conceitos matemáticos. Para realizá-lo foram utilizados métodos teóricos e empíricos; Foram utilizados os primeiros: o histórico-lógico, o analítico-sintético e o indutivo-dedutivo, para fazer generalizações em torno do tema e o segundo: a análise documental, para interpretar as aspirações e exigências metodológicas dos autores. . Seu principal resultado são as ideias teórico-metodológicas derivadas da revisão bibliográfica realizada, que deverão nortear o processo de formação de conceitos matemáticos na prática pedagógica.

Palavras-chave: conceitos; desenvolvimento do pensamento; formação de conceitos; matemática e processo de ensino-aprendizagem.

INTRODUCTION

Among the most current trends in the improvement of educational processes, one of the demands is to stimulate the formation of concepts and, with this, ensure that students develop logical thought processes and reach the theoretical level necessary to solve problems in the context. where they live and the different sciences.

From this perspective, the teaching-learning process of Mathematics has an important role, since its knowledge offers students multiple potentials for the development of skills, habits and abilities that stimulate their creative thinking (Cueva, 2022); given that understanding mathematical concepts requires a high level of abstraction (Fernández, Alfonso and González, 2017).

In this regard, Mathematics Didactics considers the formation of concepts as a complex process that requires attention to its nature and understanding (Velázquez, Villarraga, & Sigarreta, 2020) and, above all, constant improvement. According to Bueno, Naveira and González (2020), it is significant to achieve a solid conceptual, subjective and cognitive base in students, as this would allow them to understand mathematics and its applications.

Regarding the formation of concepts, Mathematics Didactics scholars insist on its relevance to stimulate logical and reflective

thinking (Angulo, Arteaga and Carmenates, 2020), to organize phases for its treatment: preparatory, training and assimilation (Pérez, Rodríguez and Songuile, 2023) and to design situations contextualized to the activities that students carry out as part of their daily life, linked to the concept to be formed (Mederos, Negrón, Sánchez and Sigarreta, 2007).

In this sense, the school programs reveal the transversality of the formation of concepts in the different units and their importance for the understanding and solution of situations in practical life and Mathematics itself. Hence, the formation of concepts is significant in the teaching-learning process of Mathematics, since it has a special role in the development of students' thinking from the earliest grades and in the explanation of various environmental problems (Ballester *et al.*, 2018).

In these positions, emphasis is placed on the concept formation phase and some of its main requirements are described. Despite this, in pedagogical practice, the results of the formation of concepts do not correspond to the aspirations of the programs; For this reason, the interest is to delve into the theoretical study of this partial process, typical of the Didactics of Mathematics.

Consequently, the objective of this article is: to expose the foundations, didactic regularities and current demands to be considered during the process of formation of mathematical concepts.

MATERIALS AND METHODS

The study carried out, based on the dialectical-materialist conception, required the use of a quantitative methodology during the research process. This made possible the use of theoretical and empirical methods. Among the theoretical ones, the following were used: the historical-logical, the analytical-synthetic and the inductive-deductive; all with the purpose of determining the foundations, regularities and demands of the process of forming mathematical concepts and, from them, making generalizations about the subject.

Of the empirical methods, documentary analysis was used, with the intention of knowing and interpreting the aspirations and methodological demands of the current governing documents, in relation to the didactic treatment of the formation of mathematical concepts.

For the bibliographic review related to the process of concept formation, a search was carried out for scientific articles published in journals indexed in databases such as: Scopus, Scielo, Redalyc and Latindex, among others, as well as books on Mathematics Didactics. For its identification, key words were used such as: concepts, concept formation and teaching-learning of concepts. For the selection of articles and texts, it was taken into account, depending on the topic under analysis, that they reflect the foundations, regularities and demands to be considered during the process of formation of mathematical concepts, as well as their relevance.

RESULTS

This section is organized, according to the ideas that coincide in the bibliography consulted, based on the foundations, regularities and criteria that are considered current requirements of the process of forming mathematical concepts.

Fundamentals of the process of formation of mathematical concepts

The formation of concepts is an essential component for the creation and development of knowledge in any area of knowledge and, in particular, for school learning. In the articles and texts published by didactics scholars, the foundations of

this important process from the different educational sciences become relevant.

By the way, it is proposed that without concepts the world cannot be understood, since they represent the basis of cognitive development and allow us to know the objects in the environment, their properties, relationships and transformations; Therefore, it is necessary that they be trained internally in the subjects (Navarro, Arrieta and Delgado, 2017).

From this perspective, it is recognized that the work with concepts is based on logic, since it is necessary to know their validity since they reflect the most general and essential properties of the objects, as well as their most significant links and relationships (Fernández, Alfonso and González, 2017). Likewise, they affirm that concepts are a special category in the teaching of Mathematics and that their adequate training ensures the relationship between this science and objective reality.

For the aforementioned authors, concepts are learned through a linguistic and rational basis, mediated by their experiences and the demands of the context and constitute a qualitatively new formation (citing Vygotsky, 1982). Meanwhile, they believe that concepts express knowledge of the essentials of the objects, facts and phenomena of reality and, at the same time, constitute a form of thought, of a theoretical nature, that derives from a generalized intellectual activity.

Therefore, according to Angulo and Arteaga (2019), conceptual knowledge is one of the basic mathematical knowledge areas, since it ensures the mental representations that students must possess to find solutions to the problems of practical life. From the above derives the interest given to the formation of mathematical concepts during the teaching-learning process.

Therefore, Angulo, Arteaga and Carmenates (2019) point out that mastery of concepts is an essential part of students' mathematical training. At the same time, they insist on its abstract character; In his opinion, they only exist in the human mind and represent objects or classes of objects with common characteristics that are related to the experience and perception of things, depending on the context.

Thus, for Bueno, Naveira and González (2020), it is necessary for students to recognize and appropriate the concepts, since these have their origin in practical needs that require man to transform reality. Furthermore, they insist on their educational contribution to the comprehensive training of students.

What has been stated up to this point allows us to recognize the relevance of students achieving an adequate formation of mathematical concepts; Meanwhile, it reveals the importance of mastering the fundamentals to consider for its didactic treatment.

Didactic regularities of the process of formation of mathematical concepts

For the Didactics of Mathematics, the study of concepts is of great interest, starting from delimiting what they consider as a concept and the aspects to take into account during their formation and assimilation. Given the objective of the article, the bibliographic review carried out delves into the first two elements.

Regarding the first element, what to understand by concept, there are several authors who offer their criteria. Among them, Ballester *et al.,* (1992) who specify that a concept is nothing more than the ideal reflection of a class of individuals, a class of classes, or relationships between individuals or classes based on their - essential characteristics.

Likewise, Mina (2007) analyzes them as the means that allows subjects to know and interpret the world; since, in his opinion, they reflect the general and essential qualities of the objects or phenomena of the environment and their relationships. Meanwhile, for Mederos and Roldán (2013) a concept is "a generalized mental model of

certain features or properties of objects, or relationships between objects grouped in a class; as well as of objects with those characteristics grouped in another class" (45).

From a similar perspective, Fernández, Alfonso and González (2017) refer those concepts "express knowledge of the essentials of objects, facts and phenomena of reality" and, also, are "a form of thought, a mental process "which constitutes a generalized intellectual activity of a theoretical nature" (p. 5) and arise from practical needs and from transforming reality.

According to Mederos, Locia , Sigarreta and Villarraga (2018), the concept is "the form of thought that reflects the substantial indications of an object or a set of homogeneous objects and that is expressed or communicated through words, both on the internal level or external" (p. 28). That is, they study the concept as "the generalized mental reflection of a class of objects, processes or relations of reality (objective or subjective) on the basis of their essential (necessary and sufficient) and invariant characteristics" (p. 32) and as an essential form of abstract thought.

Given the positions outlined, the value of mathematical concepts is recognized to achieve the comprehensive training of students and, in particular, the development of their thinking. This is why we agree with Bueno, Naveira and González (2020) when they state that concepts are "a special category in the teaching of mathematics , since they constitute the fundamental way in which mathematical thinking operates" (p. 449).

When analyzing the second element of the section, we delve into what the authors point out in relation to the formation of concepts, seen as a fundamental aspect of the teaching -learning process and as a process; Well, according to Mederos *et al.,* (2018), these are not formed immediately in students, but from the actions, experience and level of abstraction and generalization that they achieve when interacting with objects and that allow them to determine and understand their traits or characteristics. essential. It is thus inferred that, when forming a concept, the students' thinking is modified by revealing the links between the concept and reality.

According to the previous ideas, Mederos *et al.* (2020) state that a concept has been formed when, at least, the following three conditions are met: a class of common features has been determined (in mathematics, a set of essential features) that characterize the objects of the concept, they are grouped in another class the objects that satisfy the essential features and a linguistic symbol is used for the pair formed by the two previous classes, that is, to designate the concept.

Furthermore, Angulo and Arteaga (2018) consider the formation of the concept as basic for its fixation and assimilation; They recognize their potential to develop in students the ability to apply what they have learned creatively and promote their logical-verbal training. In this sense, it is analyzed that when forming concepts, various types of activities can be used: the object (manipulation and transfer), the perceptual (perception and observation), the mental (analysis and synthesis) and the verbal (designate and name); some of them, associated with the thought processes that allow identifying and establishing the common properties of an object (Angulo and Arteaga, 2018).

Regarding this process, Mederos *et al.* (2013) consider that it depends directly on the actions of the subject and their physical or intellectual activity; and that goes through forms that determine its generalization and abstraction, going from the external to the internal. Consequently, they advise that the concepts to be formed must be presented in specific contexts that allow students to make sense of them (Angulo, Arteaga and Carmenate, 2020); This element confirms the relevance of using mathematical or practical life situations that require the concept to be formed, for its understanding and solution.

When referring to the process under analysis, Bueno, Naveira and González (2020) point out that its educational contribution is based on the achievement of a solid conceptual, subjective and cognitive base that allows students to understand mathematical knowledge and that has the potential to reveal the relationship between mathematics and objective reality, an essential aspect among the objectives of Mathematics.

On the other hand, in the process of forming a concept, it is essential to analyze its content and extension as interrelated categories and it is specified that "the broader the content of a concept, the narrower its extension will be and vice versa" (Mederos *et al.*, 2018). For them, the content of the concept is determined by the characteristics that specify it and its extension, the collection of objects that fulfills them.

Then, Tocto, Vivanco and Quizhpe (2023) state that the process of forming mathematical concepts covers a large period of time and that it is systematically perfected. From the above, the importance of considering for its description and organization the phases or stages, the paths, the levels and the principles that are related in the bibliography consulted; as well as systematizing the criteria of different authors that facilitate their understanding.

In relation to the planning and execution of the didactic treatment of mathematical concepts, Ballester *et al.,* (1992) recognize three partial processes: preparatory considerations and exercises, concept formation and concept assimilation. In this article, the analysis focuses on the second, which is understood as the part of the process that leads from the creation of the starting level, motivation and goal orientation, and that goes through the separation of common characteristics and not common, until reaching the definition or explanation of the concept (Ballester *et al.*, 1992).

Likewise, it is taken into account that concepts are not formed immediately; This occurs through a process that goes through several levels: analysis-abstraction, discrimination-identification and synthesis-concretion (Ballester *et al.*, 1992).

Regarding this aspect, Mederos *et al.* (2018) make use of the stages of activity theory: orientation, execution and control. When explaining them, they are based on the five phases that Galperin points out and highlight the essential role of motivation, the need to ensure the guiding base, the potential of using models to determine the essential characteristics of the concept, the importance of achieving a sensory image of the object to be defined and its internal and external verbalization.

On the other hand, from a didactic point of view, we agree with Angulo, Arteaga and Carmenates (2020) when they propose as essential in the process of forming mathematical concepts: the stages and levels through which it passes, the paths that can be used and the principles on which this process is based. This position suggests that "a mathematical concept can be formed at a certain stage, at a certain level and then it can be expanded and deepened at higher stages and levels" (p. 299).

Subsequently, Angulo, Arteaga and Carmenates (2020) propose that the process of forming a concept does not only include the concept and its representation or image; They also point out the actions and operations that allow it to be built and identified. In this regard, they refer to three stages: the conceptual-informal, the concrete-conceptual and the abstract-conceptual and, based on them, they describe four levels that students go through during this process: the visual, the distinction, the formal and that of innovation.

In the first stage, students form a mental image of the concept; In the second, they go from image thinking to conceptual thinking and, based on the observable characteristics of mathematical objects, empirical concepts are formed (Angulo, Arteaga and Carmenates, 2020). We agree with the authors when they primarily

associate these two stages with lower educational levels.

Meanwhile, in the third stage, we move from concrete-conceptual to abstract-conceptual thinking and abstract-logical reasoning predominates; In it, based on the identification of the relevant attributes or characteristics, mathematical concepts are formally defined.

Referring to the levels for the study of the process of formation of a concept, Mederos *et al.* (2018) propose three: that of analysis-abstraction, that of identification-discrimination and that of synthesis-concretion; In these, the actions that a subject develops from the objects, their experience and the level of abstraction and generalization of their ideas are summarized.

Another element of interest for Angulo, Arteaga and Carmenates (2019) are the principles: of the relationship between mental representation and the concept of mental representation; of the interrelationship concept context contextualization; of perceptual, contextual and mathematical variability; of the interrelation between contextualized and "non-contextualized" problematic situations ; of the continuous support in the concrete and in the concepts built on the basis of experience and the interactive and cooperative nature of learning.

Next, we delve deeper into the ways to use to form a concept. In this sense, Ballester *et al.* (1992, p. 95) considers two ways. The deductive goes from the general to the particular and starts from the definition of the concept and through the analysis of examples the content is discovered; Regarding this same route, Mederos *et al.* (2018) that is essentially based on primary concepts and that a viable alternative is the introduction of doubt or contradiction about the concept to be formed, thus demonstrating its necessity and importance.

When referring to the previous route, Riascos and Curbeira (2018) agree with what was stated by the aforementioned authors and recognize as necessary elements for its use the fact that students know and understand the previous concepts, which include the concept to be formed and a high level of abstraction.

Meanwhile, for Ballester *et al.* (1992) the inductive route starts from examples and the concept is developed through explanations and descriptions that allow us to reach its explanation or definition; This transitions from the particular (content) to the general (extension). In this way, students have a fundamental role, since their thinking must be based on the new concept and through a mental process that requires analysis, synthesis, comparison, abstraction and generalization to reach its characterization or definition (Fernández, Alfonso and González, 2017). Thus, Riascos and Curbeira (2018) recommend the use of productive methods that require heuristic procedures for the use of this route.

Subsequently, Ballester *et al.* (2002) considers a third way that modifies the previous one, the constructive way: usable when it is not possible to analyze objects that are representatives of the concept to be formed since these are not known by the students and, therefore, it is required to build them. To use it, it is essential to have time and have the necessary counterexamples (Fernández, Alfonso and González, 2017).

Regarding the same theme, Villarraga, Rojas and Sigarreta (2020) coincide with the first two routes described and add a third that they call mixed, since it takes elements from the previous two. Furthermore, they argue that to decide which way to use it is necessary to consider the following principles: type of concept, ways of thinking, historical evolution of the mathematical concept, relationship with other concepts, possible applications (theoretical or practical) and students' prior knowledge.

By way of conclusion, the criterion of Mederos, Negrón, Sánchez and Sigarreta (2007) is taken up in relation to the

conditions that allow us to assert that a concept has been formed if: a class of essential properties called content of the concept has been determined and that characterizes its objects; Objects that satisfy the essential properties and objects that do not satisfy at least one of these properties have been constructed; All objects that satisfy the properties of the first class have been grouped into another class, called concept extension; A linguistic symbol is used to designate it and a definition of it is made.

The foundations and didactic regularities analyzed explain and, at times, reveal important ideas that must be considered as requirements to be met during the process of forming mathematical concepts.

DISCUSSION

In this section, the ideas that the authors of the article highlight are contrasted, based on the research process followed, and that they suggest considering when planning and executing the process of forming a mathematical concept.

Concepts constitute a main link in the development of knowledge in all science and, in a general sense, are essential for understanding the environment in which students operate by reflecting the essential characteristics of objects and their relationships; thus confirming the need to use problematic situations from practical life for didactic treatment.

Mathematical concepts arise from the needs of practice and the development of science itself, allowing the relationship between the contents of this science and reality to be established; They constitute an essential part of the mathematical training of students, they have a high abstract character and their didactic treatment offers potential for comprehensive training, through the establishment and maturation of their personality. That is why it is recognized that "they guarantee the essential theoretical basis for the assimilation and understanding of theorems, solution procedures and the interpretation of problems" (Zayas, Escalona, Estupiñán and Cedeño, 2023, p. 39).

Concepts allow us to know and interpret the world and, in turn, reflect the general and essential qualities of objects or phenomena in the environment. Mathematical concepts establish a form of thinking of a theoretical and abstract nature that reflects the characteristics of an object or set of objects.

The formation of concepts is one of the stages of their didactic treatment. This is analyzed as a process that requires the performance of actions that link the concept to be formed with the experiences of the students and requires a high level of abstraction and generalization that allows determining and understanding the essential characteristics that lead to designating the concept in relation to with acquaintances and, preferably, in spaces that encourage the exchange of subjects.

The formation of mathematical concepts is organized by phases that are interrelated and occur by levels; For its execution, different ways can be used that require the use of various types of activities that, in general, are associated with thought processes that allow contributing to the education of students and the understanding of the meaning of the concept that is intended to be formed.

In the process of forming a concept, we must highlight the role of motivation and the importance of using models that facilitate the determination of the essential characteristics of the concept that is intended to be formed; as well as the relevance of mastering the concepts with which the concept to be formed is related.

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