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Mathematical Connections Related to Exponential and Logarithmic Functions: A Literature Review

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ABSTRACT

This paper reports a review of the Mathematics Education literature related to exponential and logarithmic functions and mathematical connections. Mainly, it seeks to answer the question: What is the current state of research related to exponential and logarithmic functions and mathematical connections in the field of Mathematics Education? To answer it, the systematic review was used as a method, through which a search for research focused on the preselected theme was carried out and analyzed taking into account, mainly, the objective, theoretical approach, contribution, and the reported results. This allowed, among other things, to identify what had been done to date and what would be viable studies to carry out. The results indicate that there is still much to explore in the line of mathematical connections, in addition to the need to carry out designs close to the teacher's practice, which promotes the understanding of exponential and logarithmic functions in students, based on the making of mathematical connections.

Keywords: Exponential function; Logarithmic function; Mathematical Connections; Literature review.

ABSTRAK

Makalah ini melaporkan tinjauan literatur Pendidikan Matematika terkait dengan fungsi eksponensial dan logaritma dan koneksi matematika. Terutama, ini berusaha untuk menjawab pertanyaan: Bagaimana keadaan penelitian saat ini terkait dengan fungsi eksponensial dan logaritma dan koneksi matematika di bidang Pendidikan Matematika? Untuk menjawabnya, tinjauan sistematis digunakan sebagai metode, di mana pencarian penelitian yang berfokus pada tema yang dipilih sebelumnya dilakukan dan dianalisis dengan mempertimbangkan, terutama, tujuan, pendekatan teoritis, kontribusi, dan hasil yang dilaporkan. Hal ini memungkinkan, antara lain, untuk mengidentifikasi apa yang telah dilakukan hingga saat ini dan studi apa yang layak untuk dilakukan. Hasil menunjukkan bahwa masih banyak yang harus dieksplorasi dalam garis koneksi matematika, selain kebutuhan untuk melakukan desain dekat dengan praktik guru, yang mendorong pemahaman fungsi eksponensial dan logaritma pada siswa, berdasarkan pembentukan koneksi matematika.

Kata kunci: Fungsi eksponensial, Fungsi logaritmik, Koneksi Matematika, Tinjauan literatur.

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Introduction

The literature review is first and important a written product, which may be based on primary empirical research, research methods, theory or practical interventions, or maybe a conceptual review (Jesson et al., 2011). According to Jesson et al. (Jesson et al., 2011), this can appear as part of a thesis proposal or an article. Still, it can also be done independently, and, for this, it is necessary to define a research question. For this reason, we believe that reviewing the literature, in this case, a systematic review, is essential, because it allows us to find out what has been done so far regarding a topic in a certain

field of study, which provides, among other things, things, information on areas that still need to be investigated and that can serve as lines for future research (Jesson et al., 2011; Petticrew & Roberts, 2006). In this case, the focus has been on research related to exponential and logarithmic functions and mathematical connections.

The exponential and logarithmic functions are concepts contemplated in the Mexican curriculum (Secretaría de Educación Pública [SEP], 2017), as well as in the curriculum of various countries (for example in Colombia (Ministerio de Educación Nacional [MEN], 2006)), therefore, their teaching and learning deserve to be investigated. In addition, they are important mathematical concepts that have a crucial role in university mathematics courses, such as Calculus, Differential Equations, and Complex Analysis; however, they represent a difficult topic for students.

According to the National Council of Teachers of Mathematics (NCTM, 2013), learning with understanding is one of the current needs and interests in mathematics education. Even the NCTM (National Council of Teacher of Mathematics [NCTM], 2013) bases its Principles and Standards on the idea that students learn mathematics with understanding and affirms that the ideal is that they manage to understand mathematics in such a way that they can apply it through the use of concepts, procedures, and processes. In this context, mathematical connections play an important role, because when students can connect mathematical ideas, their understanding will be lasting (Australian Curriculum Assessment and Reporting Authority [ACARA], 2012).

In addition, the Australian (Australian Curriculum Assessment and Reporting Authority [ACARA], 2012), Turkish (Ministry of National Education, 2013), and Colombian curriculum (MEN, 1998), among others, also encourage the making of connections in the teaching of mathematics. The Mexican curriculum (Secretaria de Educación Pública [SEP], 2017), although it does not directly affirm this, for the area of mathematics in High School, it frames aspects that allude to making mathematical connections. For example, it indicates that in teaching there must be interdisciplinarity between the subjects and that mathematical knowledge cannot be isolated knowledge, but must serve as a tool for students to develop competence for life and to solve problems in other fields such as physics, biology, chemistry, economics, etc.

In this sense, from the curriculum of some countries, the importance of making mathematical connections is evident, and they even correspond with research in Mathematics Education, in which making mathematical connections is a key point for mathematical understanding (Campo-Meneses & García-García, 2021). García-García and Dolores-Flores (2021b) agree with this position, so analyzing the mathematical connections that a subject makes it possible to study their understanding. Thus, in this study it is interesting to review and analyze the research on these topics to determine what can be studied

concerning each one or together, particularly to answer the question: What is the current state of research related to the function's exponential and logarithmic and mathematical connections in the field of Mathematics Education?

Theoretical-methodological framework

In this research, mathematical connections are considered, according to García-García and Dolores-Flores (2018), as a process in which a person makes a true (mathematically consistent) relationship between two or more ideas, concepts, and theorems, procedures, meanings, etc., with each other, with real life, or with other disciplines.

This research is qualitative, mainly using the systematic review method, which, among other things, seeks to outline areas of uncertainty and identify where little or no relevant research has been carried out, particularly where studies are required (Petticrew & Roberts, 2006). To develop this method, the work carried out by Navarro and Ramírez (2018) and Oviedo and Lizárraga (2022) was taken into account, thus planning seven phases that are described below.

Phase 1. *Formulation of questions:* from the general research question posed (What is the current state of research related to exponential and logarithmic functions and mathematical connections in the field of Educational Mathematics?), questions were formulated that allow guiding the study and for each one an analysis category was defined, as shown in Table 1

Table 1. *Categories and formulation of questions*

Question	Category
Where has more research been done on these topics?	Contribution by countries
What approach has the research had?	Research approach
On what type of population have the researches carried out on connections and exponential and logarithmic functions been focused?	Population of interest
What are the frameworks or theoretical-methodological references used to carry out studies on the teaching-learning of exponential and logarithmic functions?	Theoretical-methodological referents
What have the research found contributed?	Contributions in Mathematics Education

Phase 2. *Delimitation of search terms:* taking into account the questions posed in phase 1, the following search terms were defined: mathematical connections, exponential function, and logarithmic function.

Phase 3. *Definition of the inclusion and exclusion criteria of the search:* the exclusion and inclusion criteria defined to be able to answer the questions posed are shown in Table 2.

Table 2. *Inclusion and exclusion criteria*

M,Criteria	Inclusion	Exclusion
Document Type	Articles	Thesis, book chapters, books, conference proceedings, specialized blogs.
Area of interest	Mathematics education	Areas other than Mathematics Education. In addition, those historical articles.
Approach	About the teaching and learning of exponential and logarithmic functions. About the use of mathematical connections as a theoretical reference for the teaching and learning of a mathematical concept.	Different from teaching and learning the functions or using the connections in this process.
Temporality	2018-2023	Published before 2018.
Language	Spanish and English	Languages other than Spanish and English.

Phase 4. *Selection of databases and search:* the search for articles is carried out following the previous phases. For this, databases and the web pages of the most representative research journals of our field of study, Mathematics Education, are reviewed (See Williams & Leatham, 2017). In this research, different databases such as *Google Scholar*, *Dialnet*, *Scielo*, *Scopus*, *ERIC*, among others, were reviewed, in which a variety of articles related to the terms defined in phase 2 were found.

Phase 5. *Review of the search results:* a detailed review of the studies found was carried out, to select those that are included in the previously defined topics. In this way, those studies on exponential and logarithmic functions directed at history were discarded, since they did not report elements directly related to teaching and learning. In addition, repeat investigations were ruled out. In this sense, in the case of exponential and logarithmic functions, 12 research were analyzed, and in the case of mathematical connections, 33 research were analyzed.

Phase 6. *Analysis and categorization of the selected literature:* in this phase, each research selected in the previous phase was analyzed, taking into account phases 1 and 2. In general, the selected articles were analyzed taking into account the place where it was carried out, the framework theoretical and methodological used, the type of population, the results, contributions, and areas of opportunity, which is related to the questions posed. This finally allowed a categorization according to the focus of each research.

Analysis and results

The results of the literature review have been structured, taking into account the categories of phase 1, into two groups: the literature related to exponential and logarithmic functions, and the literature on mathematical connections.

About exponential and logarithmic functions

Considering the contribution category by country, it was found that various research has been carried out on the exponential and logarithmic functions together or separately. The largest production has been in the United States and Mexico in the last five years, as shown in Figure 1.

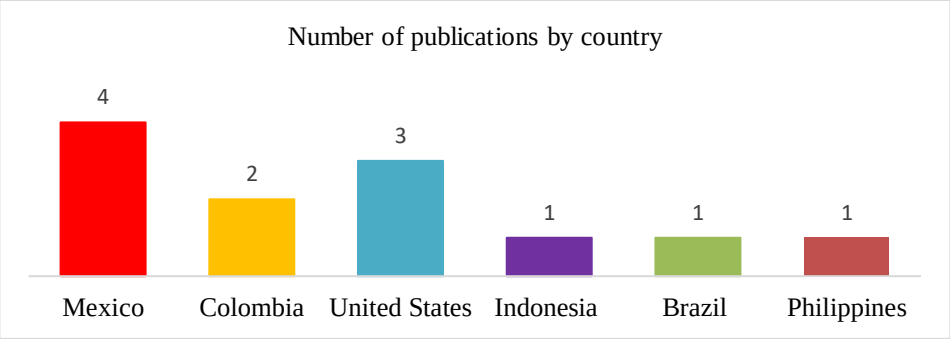

***Figure 1**. Contributions by country*

Regarding the population of interest category, it was found that the exponential and logarithmic functions have been studied in different researches focused on students (Campo-Meneses & García-García, 2020, 2021; Trejo & Ferrari, 2018) and the teacher (Campo-Meneses & Cruz, 2020; Frketic et al., 2019; Lagos, 2020). These have been carried out from the secondary level to the university, with the majority of research being at the pre-university level, followed by those at the higher level.

***Table 3.** The research found and its classification*

Population of interest	Research	Country	Theoretical reference	Research approach
Students	Trejo and Ferrari (Trejo & Ferrari, 2018)	Mexico	Covariational reasoning	Exploratory
	Kuper and Carlson (2020)	United States		
	Gruver (2018)	United States		Interpretative
	Campo-Meneses and García-García (Campo-Meneses & García-García, 2020)	Colombia	Mathematical connections	Exploratory
	Campo-Meneses et al. (2021)	Mexico		
	Campo-Meneses and García-García (Campo-Meneses & García-García, 2021)	México	Connections and mathematical understanding	Interpretive

	Silva and Almeida (2018)	Brazil	Mathematical modeling	Exploratory
	Mpofu and Mudaly (2020)	Indonesia	Commognition perspective	Exploratory
	Campo-Meneses and Cruz (Campo-Meneses & Cruz, 2020)	Colombia	Instrumental orchestration	
	Trejo and Ferrari (2021)	México	Covariational reasoning	
Books, curriculum or lessons.	Frketic et al. (Frketic et al., 2019)	United States	Lesson Design	Design for the classroom
	Lagos (Lagos, 2020)	Philippines		

There are more researches aimed at students than those focused on teachers (see Table 3). In addition, the approach of research carried out has been mostly exploratory and there are few researches that propose classroom designs or tasks to be applied in the classroom, as evidenced in Table 3. These researches have been carried out using different theoretical approaches (category: theoretical-methodological referents) among which stand out (see Table 3): covariational reasoning, mathematical modeling, commognition perspective, instrumental orchestration, lesson design, understanding, and mathematical connections, from which results have been interpreted and made contributions to the area of Mathematics Education.

In general, it has been reported that students present difficulties when solving tasks related to these functions (Campo-Meneses et al., 2021; Campo-Meneses & García-García, 2020; Trejo & Ferrari, 2018). For example, in research on covariational reasoning (Gruver, 2018; Kuper & Carlson, 2020; Trejo & Ferrari, 2018) it is stated that the study of functions should be done from the Covariation approach in such a way that it supports a construction of the exponential function based on an isomorphism between the division and counting structures, they have reported that high school students when working with exponential growth do not quantify the growth and they have difficulty reasoning continuously.

Trejo and Ferrari (2018) obtained that the students were able to identify two different variations (one for the values of x and another for the values of y), they made the change from the progression $y = 2^n$ to the function $y = 2^x$, however, did not reason about the implication of changing an "n" to an "x". Another of the difficulties identified, although along the lines of mathematical connections, are: not relating the representation registers of the exponential and logarithmic functions, not making the reversibility connection when working with graphs or for finding domain and range, and the inclination to respond to tasks on the exponential function, evidenced in university students when they solved tasks related to exponential and logarithmic functions (Campo-Meneses & García-García, 2020).

Taking into account the difficulties that have been reported in the literature on Mathematics Education when working on exponential and logarithmic functions, Gruver (2018) expressed from the line

of covariational analysis, the tasks proposed in this line can be expanded and taken to different contexts. This could be an option to address some questions about logarithmic-exponential growth, however, we consider that it is also necessary to address other aspects of the relationship between the exponential and logarithmic functions, such as their properties, characteristics in the different registers, relationship between their domains etc. In this way, we assume that it is necessary to continue searching for the appropriate elements to design tasks that promote non-numerical visualizations, which will produce a graph and promote the analysis of the continuity of the functions involved.

The literature from the covariational approach shows the importance of approaching exponential and logarithmic functions from this perspective, however, in high school there is difficulty in developing high levels of logarithmic-exponential covariation (Trejo and Ferrari, 2018), which may be due to the fact that to address this type of covariation it is necessary to have previously worked on the concept of function from this approach.

On the other hand, it is important when working with these functions, to address the representation registers and the type of relationships that can be made between them, since this is evidence, to a certain extent, of a subject's understanding of exponential and logarithmic functions. However, it is not only between registers, but also between the different objects that emerge in mathematical activity, since the make of mathematical connections contributes to the development of understanding of the subject (Campo-Meneses & García-García, 2020, 2021).

The researches whose focus has been the teaching of exponential and logarithmic functions have been directed to the teacher's practice (Campo-Meneses and Cruz, 2020) and others to the design of lessons (Frketic et al., 2019; Lakes, 2020). However, only one of these researches has been directed at exponential and logarithmic functions together (Lagos, 2020), which sought to develop and validate a module based on the understanding-by-design lesson plan for teaching these functions. However, this module is still in the process of being modified, since inconsistencies were identified in the validation (by experts, teachers, and comments from some students) and therefore it was not applied. Results such as the above show the need to propose designs for teaching these functions.

About Mathematical Connections

Mathematical connections have been the focus of interest of numerous researchers in Mathematics Education (Dolores-Flores et al., 2019; García-García & Dolores-Flores, 2018, 2021a, 2021b) and have been a key point in the curriculum of many countries such as the United States (NCTM, 2013), Colombia (MEN, 1998), Turkey (Ministry of National Education, 2013) and Australia (ACARA, 2012), among others. This is because it is considered that (1) making mathematical connections contributes to a subject's

understanding of a concept, as well as allowing them to develop other mathematical skills, and (2) studying the mathematical connections that a subject makes allows us to infer their level of understanding.

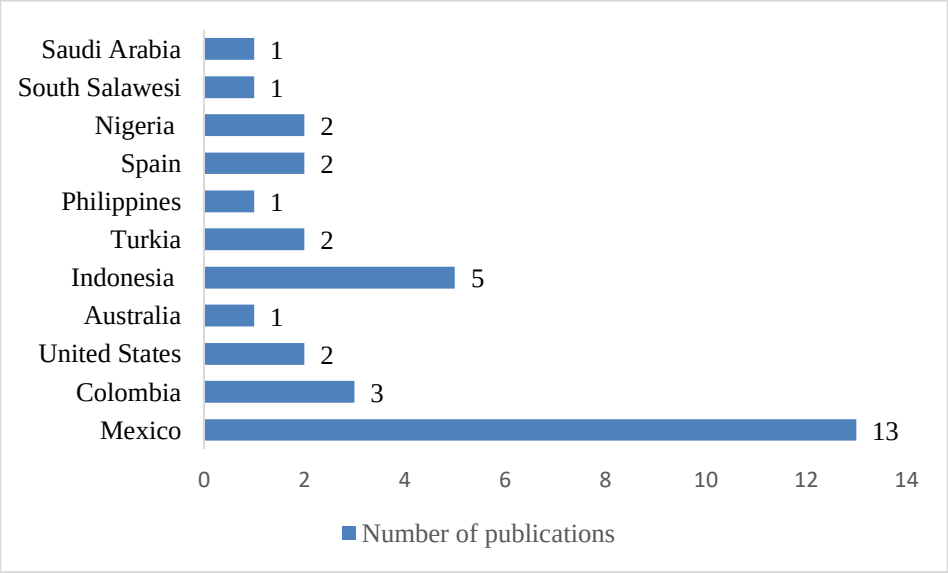

Figure 2. *Contributions by country*

In Figure 2, you can see that there is currently the largest publication in Mexico on mathematical connections. In addition, Table 4 shows that most of the research has been of an exploratory approach, which is why they have been inquiring about the connections made by the subjects or those that are promoted in the study plans, with few researches that propose designs for the classroom, tasks, interventions, among others.

Table 4. *Classification by kind of research*

Research approach		
Exploratory	**Interpretative**	**Design for the classroom**
Alabdulaziz and Alhammadi (2021); Campo-Meneses et al. (2021); Campo-Meneses and García-García (2020); Dans-moreno et al. (2022); Diana et al. (2020); de la Fuente and Deulofeu (2022); Dolores-Flores et al. (2019); García-García and Dolores-Flores (García-García & Dolores-Flores, 2021a, 2021b); García-García et al. (2022); Hatisaru (2022); Hernández-Yañez et al. (2023); Kenedi et al. (2019); Kleden et al. (2021); Lazaro and Laborte (2022); Payton (2019); Rahmawati et al. (2019); Rodríguez-Nieto, Rodríguez-Vásquez, et al. (2021); Rodríguez-Nieto et al. (2021); Saleh et al. (2018);Tasni et al. (2020); Wagino and Andriani (2021); Yigit-Koyunkaya et al. (2018); Zengin (2019).	Campo-Meneses and García-García (2021); De Gamboa et al. (2022); García-García and Dolores-Flores (García-García & Dolores-Flores, 2018); Foster and Lee (2021); Rodríguez-Nieto and Alsina (2022). Rodríguez-Nieto et al. (2020); Rodríguez-Nieto, Font et al.	Qohar and Rozak (2021).

(2021); Rodríguez-Nieto et al. (2023).

Regarding the population of interest category, it was found that the researches whose focus is the mathematical connections related to the learning-teaching process have been addressed to students, from elementary education to higher education; teachers of different levels; prospective teachers, and analysis of the mathematics curriculum. As can be seen in Figure 3, there is a greater number of researches focused on students and few those that have focused on analyzing the curriculum or another population.

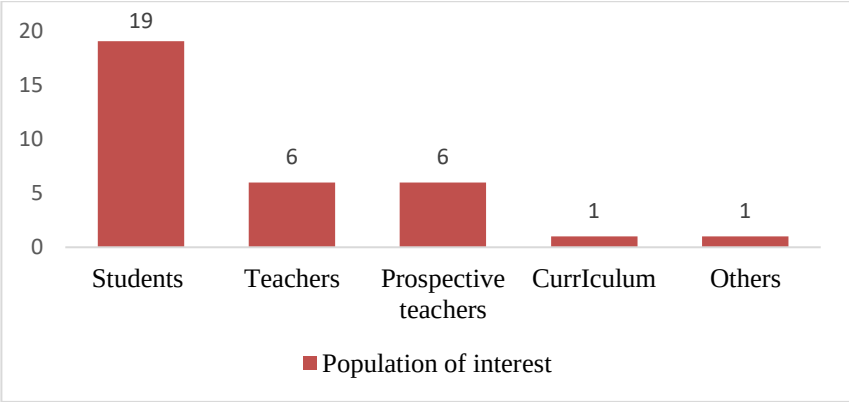

Figure 3. *Classification of research by population of interest*

Note. In this case, others refer to research whose focus was people outside the school, particularly merchants, since this research links mathematical connections with ethnomathematics.

Regarding the category contributions in the area of Mathematics Education, in general, these researches show the importance of carrying out studies under the mathematical connections approach, since they consider that its establishment contributes to mathematical understanding. However, few works aim to study mathematical understanding from this perspective. Therefore, it is necessary to carry out studies on mathematical understanding from the establishment of connections, focusing on different mathematical objects in order to explain in detail the relationship between these two processes.

In addition, it would be viable to continue analyzing whether there are other types of mathematical connections, not reported, that emerge when working with different mathematical objects, either from teaching or from learning. In the same way, explore the mathematical connections that are made when working with other mathematical objects and propose designs that promote the establishment of mathematical connections.

On the other hand, although most of the research has been focused on students, much remains to be investigated regarding different concepts that are taught in the classroom. Septian's research results (Septian et al., 2021) show that the use of learning methods has a significant effect on students'

mathematical connection abilities. Students who learn mathematics use the Jigsaw method have better mathematical connections abilities than those who do not. Likewise, it is necessary to analyze the mathematical connections that are made in math classes, in addition to analyzing textbooks, curricula, or key documents in mathematics education.

Conclusions

Once the systematic review on the exponential and logarithmic functions and on the mathematical connections was completed, we identified that the research that studies the functions as a whole is scarce and we agree with Gruver (2018) in that the interest has been directed to the study of the exponential function. Most of these researches have focused on the student, analyzing covariation reasoning, and representation registers, and understanding these when solving specific tasks. In this sense, an area of opportunity is to study the exponential and logarithmic functions together, promoting the establishment of the relationship between both. When analyzing the researches in these two lines, we consider that an interesting job could be to analyze the development of covariational reasoning in students when working with different registers of representation of a mathematical concept and in the transition from one register to another.

Given the need to develop designs, we identified some research focused on teaching, however, these are scarce and those found, to date, do not report finished proposals to take to the classroom. For this reason, we consider it viable to carry out a design in which the teacher is involved, in addition to elements reported in the literature and conceptual references such as mathematical connections, since we agree with Campo-Meneses and García-García (2020), in what to do a design fostering mathematical connections is one way to promote students' understanding of exponential and logarithmic functions.

Research on mathematical connections affirm that, from the student's point of view, making connections contributes to the development of understanding, and from the perspective of the teacher and researcher, analyzing the mathematical connections made by a subject allows assessing their level of understanding. Although these affirmations are common in various investigations, we did not find research that addresses understanding from the line of mathematical connections. In this sense, we intend to address the following question in further research: How to study and promote mathematical understanding from mathematical connections?

And taking into account the need for designs that involve the teacher, and the contribution towards the development of students' understanding of exponential and logarithmic functions, it is important to answer: What is the didactic suitability of a teaching process at the level of bachelor’s degree on exponential and logarithmic functions based on mathematical connections? And what is the progress of

the students regarding their understanding of exponential and logarithmic functions? These questions are the subject of our interest, which we will address in future investigations.

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