

The open-ended question in science, technology, engineering, and mathematics education: a mapping of scientific papers

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ABSTRACT

The aim of this study is to conduct an initial exploration of research published in academic journals dedicated to science, technology, engineering, and mathematics (STEM) education, focusing on the incorporation of problem-solving strategies and the use of open-ended questions. The analysis includes the journals *Physical Review Physics Education Research*, *Journal on Mathematics Education*, *Journal of Technology and Science Education*, and *International Journal of STEM Education*. A total of 36 articles were selected, and the methodology followed a rigorous literature review process. The results show that 64% of the selected articles focus on students in primary and secondary education. The classification of open-ended question applications reveals that 42% of the studies investigate students' characteristics, conceptions, and cognitive processes (CS), followed by 36% focusing on educational evaluation (EE). Teaching and learning processes and methods (PMTL) account for 17%, while teaching resources (DRM) and language and discourse (L&D) each make up 3%. This study contributes by providing a comprehensive overview of the interrelation between open-ended questions, problem-solving, and STEM education, highlighting relevant areas of focus such as students' cognitive characteristics and assessment practices. Future research could expand on these categories and explore teaching practices in STEM education in greater depth.

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1. INTRODUCTION

The development of teaching focused on science, technology, engineering, and math (STEM) areas have been increasing prominence in educational environments [1]–[3]. The development of competencies and skills in these areas of knowledge is directly related to education in the 21st century [4]. The work within this perspective is developed based on active methodologies that seek a broad development of students, both conceptually and in terms of skills. Among the main skills to be developed, problem-solving is at the heart of these methodologies [5], [6].

Problem-solving is present in the scientist's work and in school activities, as well as in people's daily lives. In the students' perception, there is no difference between problems and fixed exercises at the end of a chapter in books or textbooks; however, problems and fixed exercises present marked differences, whether in their proposals, their structure or in terms of their didactic objectives [7], [8].

The problem is then characterized as a complex element, without automatic resolution. Solving a problem implies the use of a protocol of rules, associated with reflections on the decisions made during the solution [9]. In this way, the objective of the problem within student learning is characterized by the development of new skills or the reorganization and application of their already existing knowledge in a new problem situation. In contrast, an exercise can be defined as a situation in which what is observed is the use of automated routines because of continuum practice [7]. This means that what is proposed to the student is already known, not necessarily the elaboration of a new skill or the development of a new routine for its resolution.

Considering a problem to be a situation in which the individual is led to perform a series of procedures, steps, and reflections to achieve a goal, Ince [7] proposes that the resolution of a problem presents three stages: initial state, objective state, and procedures to eliminate the distances between the two states. The initial state is the moment in which the individual encounters the problem and the data provided to him. The objective state is the state that the individual intends to reach, in this case, the resolution of the problem. Finally, the third stage of a problem is the procedures to be performed to solve the problem, leaving the initial state and concluding the solution proposed in the objective state.

Based on the third stage of a problem, Ince [7] classifies problems into two distinct categories: systematic problems and intuitionistic problems. Systematic problems can be solved by applying already-known procedures or routines [8]. This category of problems is characterized by the use of skills already known by the individual, so the procedures that will be performed during the resolution of the problem are, in some way, similar to other situations previously experienced by the individual. In contrast, intuitionistic problems are those whose solution requires a revolutionary change in thinking, close to a personal paradigm break, causing an intense reflection associated with a series of decision-making during the resolution of the proposed problem [7].

Works that discuss problem-solving strategies have been presented since the 1940s, presenting characteristics of the investigation of known strategies and new strategies developed for problem-solving [7]. The first step the student becomes aware of the problem and understands it from the data presented. The second and third steps are characterized by the construction, development and application of a strategy to solve the problem. Finally, the last step proposed is retrospection, a moment in which the student begins to reflect on whether the result found is what was expected, becoming the main step in problem-solving strategies [7], [10].

This strategy, presented by Polya, can be applied to problems in any area of knowledge. Over the years, works that discuss problem-solving strategies have developed studies in specific areas of knowledge. However, the greatest highlight of these works is the investigation and comparison of the strategies used by experts and novices during problem-solving.

Among the research on problem-solving strategies in STEM, one of the most important lines of research is related to the strategies used by novices and experts [8], [11]–[14], showing that the two types of individuals have different strategies to solve the same problem. The experts are individuals who accumulate greater knowledge and experience, both from a conceptual point of view and the skills needed to solve a new problem [8]. The novice, on the other hand, is the less experienced individual who does not present a broad repertoire of content and skills needed in problem-solving [8].

The main difference between experts and novices is in the familiarity with which each group observes a new problem: the experts have already had previous contact with similar problem situations, therefore demonstrating greater ease in finding the solution [14]. This familiarity allows the expert to solve the problem “by working forward from what has been given and on the way to the result” [14]. This means that while the expert takes advantage of the data in the problem and “develops the qualitative representations by working towards the mathematical relationships needed to solve the problem” [8] the novice, in contrast, works along a path that is inverse to that of the expert. This inexperienced individual has a “looking back” perspective as a way of initiating problem-solving [14]. This “looking back” is associated with the fact that the novice searches for an equation that can be used to solve the problem. The strategy for choosing the equation is supported by the data that are provided; the novice searches for an equation with the same variables that he has, without reflecting on the physical problem in question [8].

In addition to the difference with respect to the “mathematical” path used by each individual, experts and novices differ with respect to the construction of problem representations [11]. According to Ince [7], novices as they do not have extensive knowledge of the contents are forced to construct representations that are steeped in everyday or superficial ideas and resources with which they are familiar. Conversely, experts create physical representations that incorporate important concepts, principles, and physical relationships.

When solving a problem, the novice builds a representation from superficial ideas, which may be impregnated with non-scientific content. This difference regarding the construction of the representation of

the problem, between experts and novices, is of extreme importance because it is from this representation that the individual will determine which strategy to be used in solving the proposed problem. Bao and Koenig [14] discuss that novices construct their representations from a process of direct syntactic translation, this means that the individual only “translates” what is proposed in the problem, without presenting clarity about all the necessary connections to its solution. On the other hand, the experts create a physical representation of the problem promoting all possible relations between the data [14]. In this way, it becomes evident why experts solve problems looking forward, while novices look back. The importance in reflect on the different strategies of the students, promote a reflection on the objectives of the development of the skill. For skills development, it is necessary to define the best approach to start teaching. In this way, the types of problems can be used to develop different skills.

In research on problem-solving, it is very common to find problems presented to students in two modes: close-problem items and open-ended items. The close-problems questions are characterized as problems with two or more alternatives [9], [15]. However, among the answer possibilities only one is correct. The incorrect alternatives are known as distractors and represent hypotheses of reasoning developed by students [15]. In general, close-problems items are used in large-scale assessments, surveys, or knowledge tests as they facilitate the correction process and speed of feedback [16]. Despite the ease of use of this question type, experts agree that it is difficult to produce items of this type due to the construction of good wrong alternatives [9]. Thus, often the use of this type of item for assessment ends up being undermined with the use of poorly constructed problems that do not assist in the process of assessing students’ skills or knowledge.

Another type of question is known as open-ended questions, which represent problems with multiple possibilities of correct answers. This type of question allows for a broader understanding of students’ problem-solving processes [17], [18]. This type of question can be analyzed with analytical, ranking, and overall impression scoring methods [17]. Their main disadvantage is that they cannot be scored objectively like multiple choice items, as the score may differ according to the person doing the scoring [17]–[19]. The most reliable of these methods is analytic scoring (key scoring). In key scoring, answers to questions are prepared in advance and each answer is analyzed in minute detail [20].

In the teaching context, the option to use open-ended or close-problems questions depends on the teacher’s choice according to the characteristics of their students, the skills they intend to develop, the assessment instrument, and the time, among other factors. In the academic field, we find in the literature several studies that deal with the problem of problem-solving using close-problem or open-ended questions. In this way, this article supports researchers and teachers of different levels of education about problem-solving in STEM education. Our aim was to carry out “state-of-the-art” research on the use of open-ended questions in different journals in the STEM area.

State-of-the-art research is dedicated to the study of a given set of research studies, which brings together an area, a theme of interest and relevance, or even a specific field of study; they analyze, in a given period, the characteristics of historical evolution, thematic and methodological trends, the main results of investigations, problems and limitations, gaps and unexplored areas, among many other aspects that should be objects of analysis in relation to academic production in a given research area [21]–[23]. They are descriptive-exploratory research based on document analysis, because they intend, in the first moment, to identify, describe and explain certain facts or phenomena. Secondly, to establish an understanding of the meaning of this production within the context of the research area. From these searches, a catalogue or a descriptive-explanatory text may be prepared to facilitate the search for theses and articles on a given area or theme.

The catalogues and texts usually contain some basic descriptors to optimize the research work and characterize its main theoretical or methodological trends, such as the name of the author of the work; year of publication; journal, periodical or congress in which it was published; the area in which it was produced; theme of the work; theoretical framework; main results; among other descriptors. In the case of doctoral theses and master’s dissertations, the studies usually also include the advisor’s name, year of title and name of the educational or research institution where the work was developed.

In addition to the descriptors presented, the catalogues and texts may include the abstracts of the articles or theses catalogued, using the abstracts with the purpose of disseminating the works presented [22]. According to the literature, many authors attest to the fact of being careful when using only the abstracts in the search for articles, since many times the abstracts may not represent what the researchers seek to say in the articles and theses.

This article represents the initial results of a research project that aims to understand the relationship between the use of the methodology of “good questions” and student learning. They paper were developed originally by Sullivan *et al.* [24], [25]. “Good” questions are a specific type of open questions, but their definition is more detailed. We will call an open question a “good” question if it meets the following criteria [26], [27]: i) it requires more than a mere reference to known facts; ii) there are several answers that can be

accepted; iii) it provokes discussion; iv) it has a motivational function in lifelong education; v) students may learn something when they answer it and/or discuss it; and vi) teachers can learn something about their pupils from the pupils' answers.

Example: On a field, we want to fence a rectangular garden. For the fence, I have 30 meters of wire mesh. Which area can the garden have? (There exists more than one answer that can be accepted as correct, e.g. 14×1 , 13×2 , 12×3 , ..., 8×7 ; pupils do not necessarily need to restrict their proposals to natural numbers, the answer 12.5×2.5 is also correct). We can also ask for example which of the proposed gardens will have the biggest/smallest area [28].

One of the basic characteristics of good questions is that they are open-ended. Therefore, one of the aims of the research presented here was to find out whether other authors, in their work with open-ended questions, use questions that could be called "good" questions. In this way, we aimed to understand how the literature in the area of teaching and education discusses the theme. This way, in this first moment our main aim is the mapping of the papers about the use of open-ended questions in science and mathematics teaching, published in international journals with high impact factor and free access to articles.

2. METHOD

Systematic reviews are considered secondary studies, which have primary studies as their data source. Primary studies are understood as scientific works that report research results first-hand. Some authors [4], [21], [22], [29] believe that a rigorous stand-alone literature review should be systematic in following a methodological approach; explicit in explaining the procedures by which it was conducted; comprehensive in its scope by including all relevant material; and, therefore, reproducible by others who wish to follow the same approach in reviewing the topic [21], [22]. This research aimed to present a mapping of the literature on the use of open-ended questions in STEM teaching. To carry out the research, it was first necessary to select the journals that would be analyzed. Initially, we selected two databases for the research: Scopus and Web of Science. As the databases are extensive, we made the first cut in the selection: the journal's impact factor in the Education Area. Thus, we selected only the journals contained in the quartiles Q1 and Q2 of Scopus and the journals with a JRC value greater than 1 in the Web of Science. This first cut-off allowed us to drastically reduce the number of selectable journals. The second cut-off was the journals directly linked to the teaching of some area of STEM. Finally, a third cut-off was made to facilitate the analysis of the articles, as well as to help teachers from different educational levels to access the texts, so only open-access journals were selected.

Subsequently, the selection resulted in four journals: Physical Review Physics Education Research; Journal on Mathematics Education; Journal of Technology and Science Education; and International Journal of STEM Education. For greater security in data collection, we chose not to perform a bibliographic search through keywords, but to read the titles of articles in the abstracts of each journal issue. Based on this, we identified if the work covered studies on open-ended questions in the teaching of students, teachers or non-school public related to themes and contents of the STEM field. When necessary, we also read the abstract of the article to clarify any doubts. The entire organization and classification of articles were carried out using the Zotero software. After applying the inclusion and exclusion criteria, 36 works were selected to form the analysis corpus.

After the articles were selected, the full texts of the articles were read and indexed using the following descriptors created for the Centre for Documentation in Science Teaching, Faculty of Education - University of Campinas (CEDOC/FE/UNICAMP) [21]. The descriptors are divided into groups: institutional descriptors and education descriptors. For the first group of descriptors, the papers are indexed in: authors, year of publication, and journal. In the second group of descriptors, the papers are indexed in: educational level; knowledge area; type of research; main thematic focus. The least index main thematic focus has 14 possibilities of classification: curricula and programs; process and methods in teaching and learning; process and methods in teaching and learning; didactic resources and materials; characteristics, conceptions and cognitive processes of students; characteristics, conceptions and practices of teachers; teacher training; language and discourse; non-formal education in scientific spaces and dissemination; history, philosophy and sociology of science; history of science teaching; diversity, multiculturalism and inclusion; studies of scientific production; and educational evaluation.

The process used for classification was peer classification where authors independently categorize questions and then compare results and discuss together when the classifications are not the same. The classification is considered reliable from a 70% degree of correspondence between the selections [15]. For this study, the correspondence degree was 86%.

3. RESULTS AND DISCUSSION

Based on the methodology described, 62 articles had been selected, at the first round process, that dealt with STEM teaching and presented some relationship with the use of open questions. However, when we started the broad reading of the articles, we identified that some did not present a clear analysis of the use of open questions in STEM teaching. Therefore, we carried out a new cut of the articles, searching for those that proposed the use of open-ended questions in the research or teaching methodology. In the end, 36 articles had been selected for this research.

Continuing our data and analysis, we present our first result regarding how much paper selection represents in the total number of articles already published by the journals. Based on the data analysis of Table 1, it is observed that the selection of articles for the literature review varies considerably across different academic journals. For instance, the Journal on Mathematics Education had a selection rate of 9.83% of articles relative to the total number of publications, indicating that a significant portion of its publications met the relevance criteria for the research in question. In contrast, the International Journal of STEM Education, despite having 338 publications, did not have any articles selected, which may reflect a lower alignment of its content with the objectives of the review. Other journals, such as Physical Review Physics Education Research and Journal of Technology and Science Education, showed more modest selection rates, 0.84% and 1.62%, respectively, suggesting comparatively lower relevance. These findings highlight the importance of a careful selection of sources to ensure a robust and representative literature review on the studied topic.

Table 1. The number of articles selected and each journal, the total number of publications and percentage

Journal	Paper selected	Total paper publishes	%
Physical Review Physic Education Research	8	950	0.84%
Journal of Technology and Science Education	5	247	1.62%
Journal on Mathematics Education	23	234	9.83%
International Journal of STEM Education	0	338	0%

The second item of data that we will highlight is the distribution of articles throughout the analyzed period. For the presentation of this data, Figure 1 was produced, which describes a total of selected articles in each period analyzed. The analysis of the data presented in the chart highlights the variation in contributions from different academic journals to literature review studies over the years. The Journal on Mathematics Education proved to be one of the main sources of selected articles, especially during the 2011-2013 and 2017-2019 periods, where its contributions reached approximately 10% and 16%, respectively. This reflects the consistent relevance of this journal in the literature on mathematics education, demonstrating its central role in knowledge production and dissemination of significant research in the field. In contrast, the Journal of Technology and Science Education and the Physical Review Physics Education Research showed more sporadic contributions, with peaks in specific periods, suggesting that the interest in topics related to these publications may have fluctuated over time.

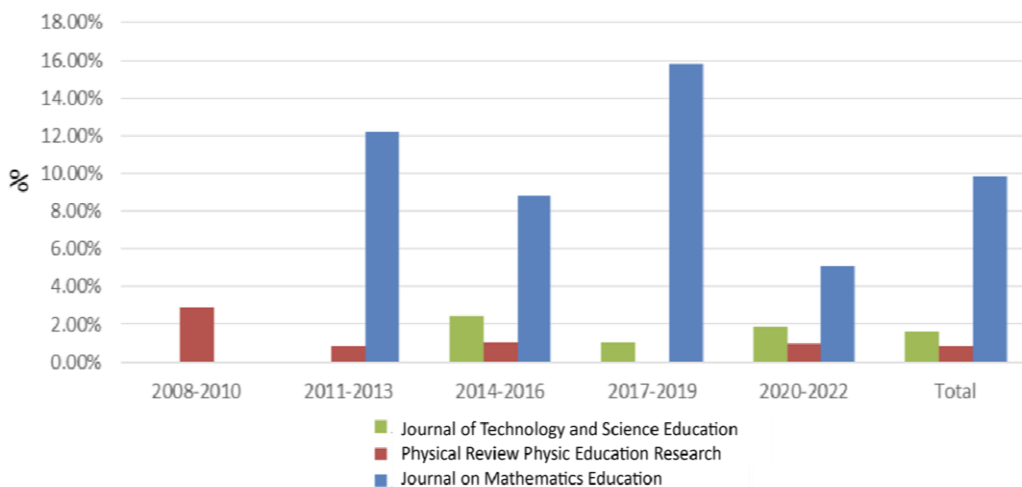


Figure 1. Percentage of articles selected in journal by time range

Considering the most recent period (2020-2022), a renewed interest can be observed from the Journal of Technology and Science Education, with approximately 5% of selected articles, while the Physical Review Physics Education Research maintained a more modest participation. The continuous contribution of the Journal on Mathematics Education underscores the importance of this journal in comprehensive reviews that aim to map the development of literature in mathematics education. This data highlights the need for a careful selection of sources when preparing a literature review to ensure representativeness and the necessary depth in the analysis of the topics in focus.

The data presented in Figure 1 indicates that although there is a gradual increase in the absolute number of articles devoted to open-ended questions in STEM, their proportion compared to other topics is not growing. This increase can be associated with new perspectives of teaching proposed as active methodology, development of problem-solving skills and soft skills [29], [30].

Regarding the population used in this research, we use Figure 2 to show this distribution. All 36 articles dealt with only one age group at a time, so the distribution is disjunctive and there is no multiple counting of any of the articles. The analysis of the presented in Figure 2 indicates the distribution of article participation in the journal selected according to the educational levels of the students addressed in the studies. University students account for the largest proportion, with 36.1% of the selected articles, highlighting a significant focus on research related to higher education teaching practices and issues. Secondary school students follow with 30.6%, demonstrating considerable interest in understanding the practices and methodologies applied at this educational level.

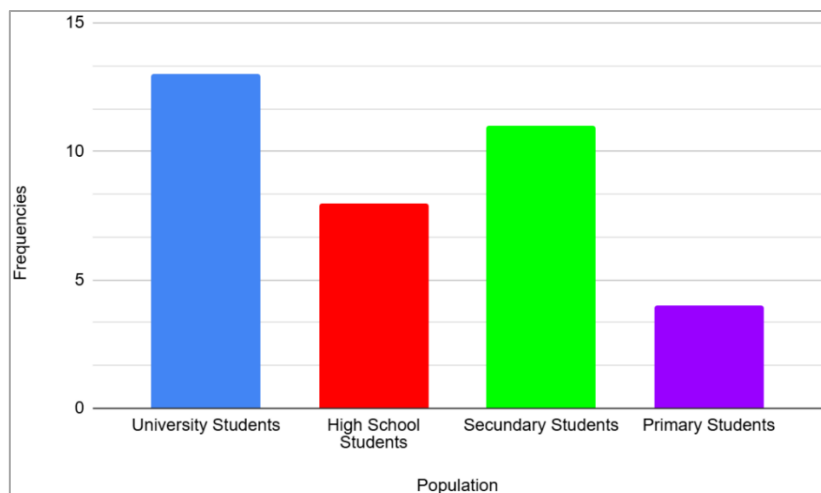


Figure 2. The concentration of selected articles concerning the research population

High school students represent 22.2% of the articles, while primary school students make up 11.1%, showing a lower emphasis on investigations focused on the early years of basic education. These data suggest that, although all educational levels are considered in the literature, there is a tendency to focus more on higher education, possibly reflecting the complexity and diversity of teaching practices and challenges in this context. This highlights the importance of future studies that more broadly address the specificities of each educational level, especially the less-explored ones, to ensure a more holistic view of teaching practices and their impacts.

Another data survey refers to the type of analysis presented in the articles. In this regard, we classified the articles into three types of analysis: qualitative, quantitative, and mixed. The data concerning this classification is described in Figure 3. The data allowed a more general analysis of the academic production regarding the use of open-ended questions in STEM content and subjects. Initially, the data presented in Table 1 indicate a tendency of the Journal on Mathematics Education to publish articles on the subject investigated in this research.

Another important fact refers to the populations investigated in the articles. As shown in Figure 2, we observe that the largest concentration of published articles conducted research with university students (36%). However, this data does not reveal the main concern of the research on open-ended questions. This is because if we look more closely at the data in Figure 2, we find that the largest percentage of publications refers to research with primary, secondary and high school students. Thus, this data reveals an important concern and has

already been described by some authors about the development of skills related to education in the 21st century, especially in basic education [1]–[4], [29], [30]. Some that discussion about the development of these skills is associated with some key implications for educational practice. First, early intervention, the findings suggest that developing problem-solving abilities should begin in the early years of schooling. This approach can lay a strong foundation for future academic success and personal growth [29], [30]. Secondly, assessment, traditional assessments often focus on memorization and recall. To effectively measure problem-solving skills, educators should employ authentic assessments that require students to apply their knowledge to solve complex problems [9]. Third, collaborative learning environments can foster problem-solving skills by encouraging students to work together, share ideas, and develop different perspectives [5].

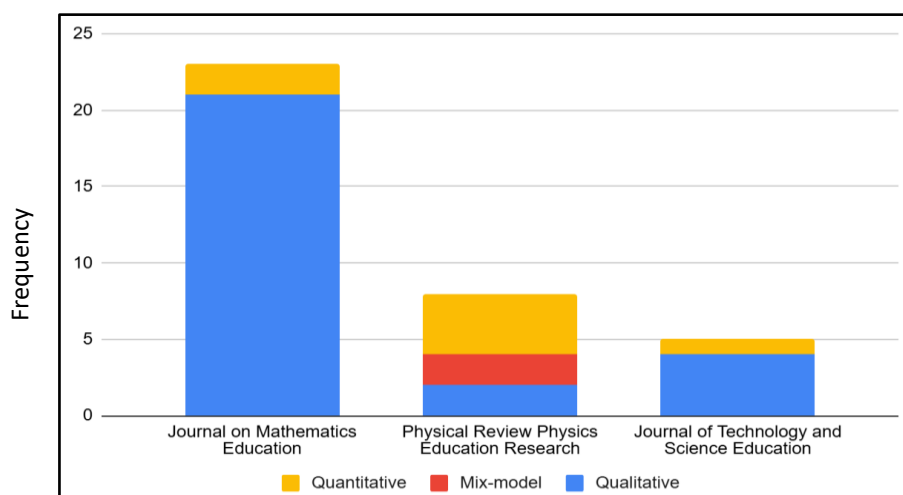


Figure 3. The number of articles is classified according to the type of analysis presented in the selected articles

Regarding the data presented in Figure 3, we observe that most articles present a qualitative analysis of the research results, indicating a greater concern with the quality of the activities developed than with the generation of numerical data with or without qualitative analysis of the work developed. However, it is important to highlight that there is a preference on the part of some journals to publish more articles on a certain type of research. The higher percentage of quantitative papers published in Physical Review Physics Education Research (50%). This result represents a tendency of the journal in publications with this type of research approach. It is an important indication of this tendency of the journal because quantitative research is necessary for the development of the research area. In the other two journals analyzed, we found a percentage of over 80% of articles published with qualitative research. By combining qualitative and quantitative methods, researchers can gain a more comprehensive understanding of educational phenomena. This type of separation and presentation of the data allows better visualization of the characteristics of the research on the topic of open-ended questions in STEM education.

Still, concerning the analyses we produced on the data presented, we then move on to the presentation of another qualitative analysis of the articles selected. In this sense, we sought in the articles to identify which applications had been used in research with open questions in STEM education. For this, after reading the articles in detail, we classified them using the descriptions presented in the methodology topic. The data from this classification are presented in Figure 4.

The data analysis reveals a strong bias among researchers towards understanding the cognitive processes and individual characteristics of students. The category “characteristics, conceptions, and cognitive processes of students” concentrated most of the research, evidencing a growing interest in how students learn and the factors that influence their performance. In parallel, the category “educational evaluation” also stood out, reinforcing the importance of assessment as a tool to monitor student progress and guide pedagogical practices. This dual emphasis reflects a trend towards a more personalized and student-centered education, where assessment plays a central role in tracking the individual development of each student.

The analysis also reveals the diversity of interests within the field of educational research. Although the categories “characteristics, conceptions, and cognitive processes of students” and “educational evaluation” have predominated, the remaining categories demonstrate the existence of a broad and dynamic research field. The lower frequency of research in the categories “didactic resources and materials” and

“language and discourse” indicates opportunities for future investigations, such as the development of innovative teaching materials and the analysis of language used in the classroom. These areas, still relatively unexplored, can contribute significantly to improving the quality of teaching and learning.

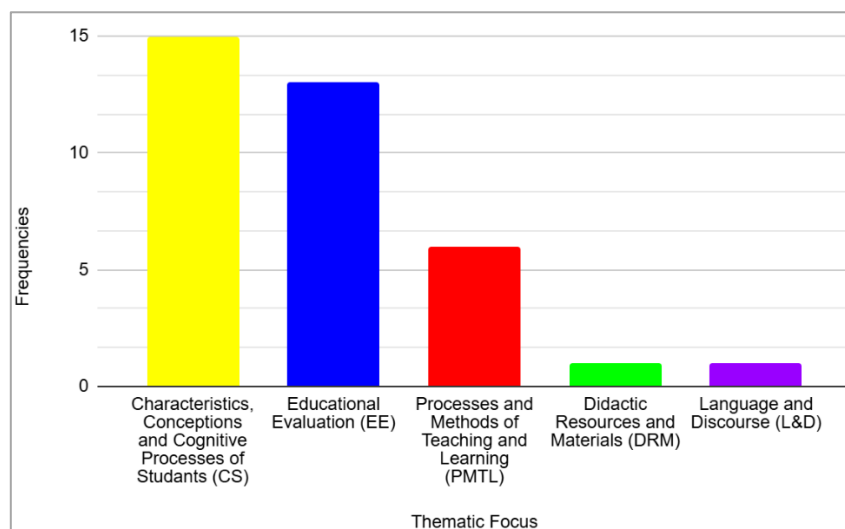


Figure 4. Frequency of searches classified under characteristics, conceptions and cognitive processes of students (CS); educational evaluation (EE); processes and methods of teaching and learning (PMTL); didactic resources and materials (DRM); and language and discourse (L&D)

The data presented in Figure 4 indicate two main types of the application of open-ended questions in the surveys, CS and EE. The first type CS (39%) represent the: identification of students' prior knowledge, their intellectual structure, models of thinking or their conceptions/perceptions/representations about science, methods of scientific production, environment, health, sexuality or about specific themes, contents or concepts. In the context of the STEM area all papers classified as CS are interested in the development of skills directly related to the proposals for STEM teaching, linked to education in the 21st century [3], [4].

In the case of several papers [31]–[37], they are interest in describe the attitudes and characteristics of a student or group of students in the context of teaching and learning processes. These studies focus on the student's attitudes towards the solution of a problem. If problems are too easy or too hard, use of the template no longer consistently correlates with student's scores on the problem; context-rich problems or synthesis problems are good problems to practice this with, as they require students to think more carefully about the features of the problem than typical textbook problems; authentic problems contain other elements, such as irrelevant or missing information, that make certain suggested strategies; e.g., identifying relevant physics concepts, identifying and making assumptions, and developing abstract representations; more difficult for students [31]–[35].

Previous studies [38]–[40] describe and analyze the development of scientific concepts in the thinking of students, implying processes of conceptual change or evolution. Other studies [16], [41]–[44] describe the relationship between the cognitive structure of students and the teaching and learning process of scientific concepts in formal education processes. The papers results indicated that the higher degree of uncertainty on the problem definition or on an activity description, the more often association is attempted through individual repertoire, covering more varied options. In the case of a tight briefing, the creative effort appears to be overlapped by the execution of simple operations, resulting on a deviation from the required goal [38]–[40].

The second type EE (36%) represents the studies on the evaluation of the teaching and learning process in its dimensions: evaluation of learning, institutional evaluation, systems evaluation and large-scale. In general, the open-ended questions used for this type of research had as reference the characteristics of the Programme for International Student Assessment (PISA) questions. Several studies [45]–[57] use of open-ended questions to the development of skills and techniques to be used in the resolution of problems generally applied in standardized assessments. Based on the analysis of students' answer, the developed problems display potential effects on student's diverse basic mathematical abilities on the various process of answering the problems. The basic mathematics abilities emerging among which are reasoning and argument

ability. It appears that students can develop and solve the problem by modeling using their assumptions. Also, the other ability is designing strategies to solve problems in which students use various procedures in solving problems leading the conclusion [45]–[51]. It is shown from their work in solving problem where all of the indicators of problem-solving competency have emerged quite well category. In addition, based on interview result from some students, known that they like to do such tasks because can improve their reasoning, creativity and thinking ability [52]–[57].

The third type identifier is PMTL (22%) research that analyze the content-method relationship in science teaching, focusing on the scientific knowledge conveyed in school, the way this knowledge is disseminated methods and strategies for teaching and learning, or even the perspective of inseparability between form and content in educational processes. Several researchers [58]–[61] have focus an elaboration and application of methods and strategies in teaching associated with open-ended questions. Previous studies [62], [63] have focused on proposing alternative methods for teaching, or that describe and evaluate pedagogical practices and the teaching methodology in them. The DRM (3%) describe the evaluation studies of materials or didactic resources in science teaching, such as reading texts, textbooks or paradidactic, textbooks, laboratory materials, films, videos, documentaries, computer, games, toys, platforms and virtual environments, conceptual maps among others. In this case, Solórzano [64] proposes, applies and evaluates new teaching material. The L&D (3%) are studies on theories of language, text and discourse; discursive approaches and interactions in teaching and learning processes in science and mathematics education; argumentation, cognition, reading and writing in the teaching and learning of contents and concepts [65]–[67]. In our classification, the research of Wilson *et al.* [65] developed a classification of open-ended responses using natural language processing.

In the same way that we sought to analyze which types of research are most published by each journal, we also analyzed how each journal published papers according to the types of descriptions presented. Analyzing the data in Table 2, we observe that 50% of Physical Review Physics Education Research published is related to CS and 37.5% of the papers are related to PMTL. This indicates a characteristic of this journal in publications that seek to develop activities with students at different school levels, as well as in the dissemination of new teaching proposals for education. The Journal of Technology and Science Education showed a low number of published papers within the parameters of this research, however, the data in Table 2 point to a more paper classified as CS. The same number of papers classified as PMTL and DRM.

Finally, the Journal on Mathematics Education was the journal that presented the highest number of selected papers. We observed that around 35% of the papers discuss the studies about concepts of the students, which makes up for the high rate of articles on this theme presented in Figure 4. However, the descriptor that is most identified in this journal is EE (57%). This result may reflect a tendency in publishing research results associated with the advancement of activities aimed at conducting large-scale examinations. This hypothesis is strengthened when we analyze the titles of the papers published by the journal available in Table 1. Of the 23 selected articles, 13 articles present in their titles the term PISA-Like which refers to the use of questions like those of PISA.

The in-depth analysis of Table 2 reveals an intricate relationship between these two constructs. Corroborating the findings of Ince [7], the high frequency of the descriptor CS indicates a growing interest among the academic community in understanding how students construct meaning from learning experiences. In turn, the significant presence of EE demonstrates the importance of assessment as a tool for investigating these concepts and informing pedagogical practice. This relationship is fundamental because, as argued by [3], [7], assessment is not limited to measuring performance but can also be a tool to promote learning and the development of critical thinking.

Table 2. The number of articles published by journals is classified into descriptors

Journal	Classification	Frequency	Number of papers select	%
Physical Review Physics Education Research	CS	4	8	50
	EE	0		0
	PMTL	3		37.5
	DRM	0		0
	L&D	1		12.5
Journal of Technology and Science Education	CS	3	5	60
	EE	0		0
	PMTL	1		20
	DRM	1		20
	L&D	0		0
Journal on Mathematics Education	CS	8	23	34.8
	EE	13		56.5
	PMTL	2		8.7
	DRM	0		0
	L&D	0		0

4. CONCLUSION

Problem-solving and the use of open-ended questions are central themes in the teaching of STEM content and skills. Research in this area has gained prominence in recent years, allowing new reflections on pedagogical practices. This study conducted an initial survey of articles published in high-impact journals in the STEM education field, following a rigorous methodology. Four open-access journals were selected: Physical Review Physics Education Research, Journal on Mathematics Education, Journal of Technology and Science Education, and International Journal of STEM Education. However, only 36 articles met the established criteria, with no articles selected from the International Journal of STEM Education, while the Journal on Mathematics Education was the most representative, contributing 23 articles.

The data indicated a significant increase in publications on the topic after 2018, with 50% of the selected articles published during this period. This growth is linked to expanding discussions around STEM teaching and the development of problem-solving skills. It was observed that 64% of the research focused on students in basic education (primary, secondary, and high school), with high school receiving particular attention (31%), reflecting a concern with fostering these skills from an early stage. Simultaneously, considerable attention was paid to professional training in STEM areas, with 36% of studies conducted at the higher education level.

Regarding research methods, over 70% of the studies adopted qualitative approaches. Nonetheless, Physical Review Physics Education Research stood out for publishing 50% of its papers with quantitative research, demonstrating an openness to diverse methodological approaches. The thematic analysis revealed that most articles explored “students’ characteristics, conceptions and cognitive processes” (39%) and “educational evaluation” (36%), highlighting a focus on personalizing education and assessing learning processes to guide pedagogical practices. Moreover, methodological diversity was notable, with categories such as “didactic resources and materials” (3%) and “processes and methods of teaching and learning” (17%) revealing gaps and opportunities for further research. These findings underscore the need to expand studies in less-explored areas, such as the development of innovative teaching materials and discourse analysis in STEM education. Finally, the findings provide a significant overview of the intersection between open-ended questions, problem-solving, and STEM education. It is hoped that this study will contribute to expanding the field, offering a robust foundation for advancing educational practices that prepare students for complex, real-world challenges, fostering a more comprehensive education aligned with the demands of the 21st century.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Marcom Bruno						✓				✓	✓			
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Ribeiro Baldim Antonin	✓	✓			✓	✓			✓	✓	✓			
Jancarik														

C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : Writing - **O**riginal Draft

E : Writing - Review & **E**ditng

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author, [GSM], on request.

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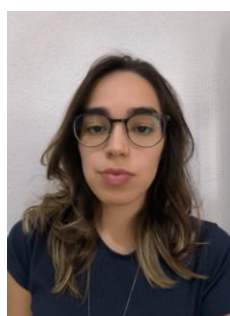
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