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A Systematic Review of Smartphone Use in Brazilian Physics Education: Potentials and Limitations

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ABSTRACT

This paper presents a Systematic Literature Review (SLR) regarding the use of smartphones in Physics Teaching. After the selection of Brazilian journals on Physics Teaching and Science Teaching with high CAPES Qualis in the four-year period 2017-2020, the initial search yielded 278 articles, which were subsequently filtered down to 51 open-access papers that were analyzed in the SLR. The analysis revealed that most of the studies utilizing smartphones are related to experimental practices, covering various topics in Physics across different educational levels, with a particular emphasis on Secondary and Higher Education. Furthermore, this study enabled the mapping of the potentials and limitations identified by the authors of the reviewed works when using smartphones as an educational resource. Regarding the potentials, we highlight: (i) the connection of lessons to everyday and real situations; (ii) increased student engagement; and (iii) improvement in learning outcomes. In terms of limitations, it was noted that smartphones: (i) present certain technical obstacles related to the sensors used; (ii) can become highly distracting when misused and poorly mediated by the teacher; and (iii) face some resistance from teachers or school management. It is expected that this SLR may serve as a reference for future research, as well as support the work of teachers, academics, and researchers interested in the topic, who recognize the smartphone as a potential ally in enhancing the quality of the teaching and learning process in Natural Sciences, especially in Physics education.

Keywords: *Smartphone; Physics Teaching; Digital Technologies; Systematic Literature Review.*

INTRODUCTION

There is a consensus among teachers and researchers that Science Teaching has been facing challenges, as well as the current educational system grappling with various difficulties. As Ribeiro (2022, p. 1) emphasizes:

> "With the constant technological growth in society, driven by the dynamism with which information is shared and disseminated, it is evident that education has become outdated in various areas." (Ribeiro et al., 2022, p. 1, our translation).

Some indicators of this include a lack of interest among students, teachers' difficulties in addressing abstract concepts, and students' failure to assign meaning to what is discussed in class, among others (Ramos, 2011; Steidtmann, Kleickmann & Steffensky, 2022).

In particular, within the context of Physics Teaching, this problematic situation has been recognized, leading researchers and teachers in the field to reflect on its possible causes and to propose new pedagogical methodologies that could address or mitigate these challenges. For example, Ramos (2011) points out that the traditional teaching methods employed by Physics and Chemistry teachers have not been very engaging for students. According to him, this directly impacts the lack of success in understanding concepts in these areas, highlighting an outdated teaching and learning process in relation to the needs of the students themselves.

In this context, traditional teaching—almost exclusively based on lectures and the transmission of information, where teachers discuss the subject matter and, at the end of the class, provide a list of exercises for students to complete, as noted by Ribeiro, Pigosso, and Pastorio (2019)—has resulted in difficulties in connecting the content studied in the classroom with students' real-life experiences and prior knowledge. In other words:

> "Many criticisms are often directed at the Physics curriculum in high schools. Perhaps the most striking is its disconnection from the students' lived reality, which results in the production of texts and teaching materials that are equally or even more detached from that reality." (Erthal & Gaspar, 2006, p. 346, our translation).

Therefore, one of the challenges in the context of Physics Teaching is to seek alternatives to traditional teaching, promoting a redefinition of the classroom environment, both in terms of the role of students and the overall classroom dynamics, particularly in the actions of teachers.

Among the various possibilities developed by research in the field of Physics or Science Teaching, the integration of innovative teaching methodologies (such as active methodologies) with resources from Digital Information and Communication Technologies (DICT) has been identified as a potential alternative (Hasas et al., 2024; Nguyen, Williams & Nguyen, 2012; Testa, 2023).

More specifically, when we look at DICT, the use of smartphones and various associated applications has been proposed and investigated in the field of research in Physics Teaching in recent years. For example, in her master's thesis, Fagundes (2019) points out that certain didactic sequences utilizing smartphones demonstrated significant advantages regarding their use in the classroom, emphasizing that students were highly engaged with the investigations and discussions proposed. Additionally, Santos et al. (2017), based on their study, concluded that using smartphones in classroom activities led to increased student engagement, as well as strengthened the mediation provided by the teacher, thereby contributing to the construction of the teaching and learning process.

More broadly, DICT in Physics Teaching are associated with the use of technological resources that aim, among other things, to facilitate access to and dissemination of information, as well as to assist in the communication process. These technologies include radio, television, the internet, mobile phones or smartphones, computers, and tablets, along with their functionalities such as audio, video, simulations, software, applications, and other tools that can be utilized in the educational context.

In this regard, Martinho and Pombo (2009) and Shan Fu (2013) state that the use of DICT motivates students and creates an environment in which learners exhibit greater dedication and commitment to the class, leading to significant improvements in assessment results. Another potential benefit of using DICT lies in the ability to overcome teachers' difficulties in addressing abstract concepts and phenomena in their lessons. Macêdo (2009) asserts that computational simulations can help mitigate this issue, as they allow students to observe phenomena and vary parameters, enabling them to see how these changes affect the phenomena under study. Furthermore, the author emphasizes that virtual experiments can be repeated numerous times in various scenarios, allowing students to create and test different hypotheses.

Given what has been presented, we recognize the importance of integrating DICT into teaching and learning practices, particularly in Physics Teaching. However, there are several obstacles that hinder teachers from utilizing these resources. One major barrier is the lack of technological infrastructure in schools. Specifically, the inadequacy of computer laboratories, which often do not have enough computers for all students or are in constant need of maintenance. Chinellato (2014) and Oliveira (2014) — in their respective studies involving interviews with teachers — highlighted these issues, revealing that the majority of the interviewed teachers did not use computers in their classes due to factors such as: (i) a lack of training and preparation among teachers, (ii) the fragility and instability of the computer laboratory infrastructure, as well as internet-related issues; and (iii) the absence of a technician or individual capable of managing the laboratories.

Considering these challenges, one alternative to integrate DICT into the teaching and learning context of Physics is to utilize a resource that students already use and have technical experience with: the smartphone. In this regard, research conducted in 2023 by the Center for Studies on Information and Communication Technologies (CETIC, 2023) shows that 95% of Brazilian households have a mobile phone, making this the most accessible device related to DICT for Brazilians.

Furthermore, in another study conducted by CETIC (2019) involving students in the 5th and 9th grades of Elementary School and the 2nd year of High School from urban, public, and private schools, it was found that, on average, 97.5% of students used their mobile phones to access the internet in 2019, while 43.5% used laptops and 40.7% used desktop computers for the same purpose. Additionally, the study shows that 84.4% of students consider their mobile phones to be the primary device for internet access.

Based on these quantitative data, we observe that smartphones are the most commonly used devices for accessing information, as they are the primary—and perhaps the only—means of internet access for many people in Brazil.

In this context, it is important to emphasize that smartphones are already used by students in class as tools for Internet searches, accessing social networks, and other purposes that are not directly related to the lesson topic (Borba & Lacerda, 2015). On the other hand, these devices also offer various features that can be beneficial in supporting instructional development. Therefore, it is one of the teacher's responsibilities to create a suitable and instructive plan to integrate this resource into classroom activities, fostering a formative process that is coherent and aligned with the needs of these individuals.

For example, one way to harness the educational potential of smartphones is by using applications available in app stores. In this regard, Borba and Lacerda (2015) discuss the possibility of utilizing these educational apps. The authors emphasize the need for this topic to be the focus of research and continuing education courses for teachers, aimed at stimulating the development of ideas that explore the integration of these tools into the educational landscape.

In light of this possibility, it is essential that teachers are aware of the potentials, limitations, and findings of research on this topic. At the same time, it is crucial that these professionals develop the necessary skills to use the smartphone critically and creatively in the classroom. Within this context, this study aimed to answer the following research question: How has the smartphone been used in didactic activities in Physics teaching, according to articles published in Brazilian journals with the highest evaluation in Qualis CAPES 2017–2020?

Therefore, with the aim of contributing to the development of this topic, we conducted a Systematic Literature Review (SLR) to present an overview of the articles published in highly rated journals of Science Teaching and Physics Teaching according to the Qualis CAPES evaluation for the period of 2017-2020. This review addresses or proposes the use of smartphones in didactic activities in the classroom, examining the following aspects: the main applications used, the Physics content most frequently addressed in this context, the teaching strategies employed in these studies, as well as the potentials and challenges identified by the authors regarding the use of these resources.

METHODOLOGICAL FRAMEWORK

This study is characterized as qualitative research, as one of its features is "[...] to collect, integrate, and present data from various sources of evidence as part of any study" (Yin, 2016, p. 31, our translation). We chose qualitative research because this approach allows for the exploration of a wide range of topics, from the simplest to the most complex, and offers flexibility in selecting areas of interest, a factor that is more constrained in other research methods (Yin, 2016).

Qualitative research encompasses various methodological approaches, such as case studies, participatory research, action research, ethnography, and interpretative research, among others. For this study, we opted for the interpretative methodological approach. According to Erickson (1986), this term is: (i) more inclusive; (ii) does not imply that the research is fundamentally non-quantitative; and (iii) emphasizes the essential characteristic of these approaches, which is to focus on human meaning, social life, clarification, and exposition by the researcher. Thus, grounded in the principles of qualitative research and guided by an interpretative methodological approach, this investigation was conducted through a Systematic Literature Review (SLR), aiming to identify, analyze, and interpret recurring patterns in academic publications on the subject.

In this context, the Systematic Literature Review (SLR) is a type of review study characterized as "[...] a form of research that uses literature on a particular topic as its data source" (Sampaio & Mancini, 2007, p. 84, our translation). According to Siddaway, Wood, and Hedges (2019), SLRs can be classified as systematic reviews involving: (i) meta-analysis; (ii) narrative reviews; and (iii) meta-synthesis. For this study, we classified the SLR to be classified as a meta-synthesis. This type of SLR aims to "[...] synthesize qualitative studies on a topic in order to identify key themes, concepts, or theories that provide new or more powerful explanations for the phenomenon under analysis" (Siddaway et al., 2019, p. 756).

The development and structuring of a systematic literature review (SLR) occur through several stages and processes. According to Sampaio and Mancini (2007), these stages are: (i) defining the research question (research problem); (ii) searching for evidence, which begins with the "[...] definition of terms or keywords, followed by search strategies, defining databases and other sources of information to be researched" (Sampaio & Mancini, 2007, p. 85, our translation); (iii) reviewing and selecting the studies to be analyzed, as well as excluding those deemed irrelevant; (iv) analyzing the methodological quality of the selected studies; and finally, (v) presenting the results.

As a data analysis procedure for this review, we adopt the strategy proposed by Yin (2016). This strategy consists of five stages, which are: (1) compilation; (2) decomposition; (3) recomposition; (4) interpretation; and (5) conclusion (Yin, 2016). Although this procedure is typically applied to case study research, we consider that it can be used and be used as a framework to organize the qualitative synthesis of this SLR.

The first stage of data analysis (compilation) involves classifying the obtained data, that is, organizing the data in a systematic manner. This compilation stage can be considered the formation of a database. In the decomposition stage, we break down the previously compiled data into smaller fragments or groups. The third stage (recomposition) involves reassembling the data. This recomposition can be facilitated by representing the data in alternative forms, such as graphs, lists, or tables. In the interpretation stage, we interpret the previously recombined data, creating new narratives. Tables and graphs can be used to assist in this interpretation. During the fifth and final stage, it is necessary to draw conclusions regarding the interpretation of the data carried out previously.

METHODOLOGICAL PROCEDURES

In the first step of developing a systematic literature review (SLR), it is essential to define a research problem that will guide the work (Sampaio & Mancini, 2007). For this reason, and considering the objective of the present research, this study sought to answer the following question: How has the smartphone been utilized in didactic activities in Physics Teaching, according to articles published in highly rated Brazilian journals according to the *Qualis* CAPES evaluation from 2017 to 2020?

In the second step, we need to search for evidence to support the research (Sampaio & Mancini, 2007). To do this, we began by establishing selection parameters for the journals to be consulted. Thus, we opted for the Sucupira Platform[1], which is a tool that collects information and serves as a reference base for the National Graduate System (SNPG). Within this platform, we accessed the Qualis CAPES, which is a system for classifying the scientific production of graduate programs concerning articles published in scientific journals, both national and international.

Using this system, we narrowed our search to Brazilian, open-access journals that had the highest ratings in the Qualis CAPES evaluation for the period from 2017 to 2020[2]. In this way, we sought journals classified as A1, A2, A3, or A4. Another restriction applied to the selection was based on the field, limiting our search to journals in the broad area of Education, specifically in the subfields of Physics and Science Teaching. By implementing these criteria, we arrived at a total of 26 journals selected for analysis.

After selecting the journals, we proceeded to select articles. For this process, we defined the time frame for articles published between January 2014 and April 2024, covering approximately the last ten years. At this stage, we also determined the descriptors[3] to optimize the search. The established descriptors were: (i) smartphone; and (ii) mobile phone. To conduct the search for these descriptors, we used the search fields on the websites of the selected journals[4].

After completing the search in all the selected journals, we found a total of 278 articles that mentioned the established descriptors. However, many of the identified articles were irrelevant to the investigative objective of this systematic literature review (SLR). To address this issue, and based on the third stage of producing an SLR (Sampaio & Mancini), we conducted a review of the selected articles to exclude studies that were of limited relevance for our research by applying a filter aligned with our objectives.

Thus, to assist in the article selection process, a filtering system was established. We began by filtering out all texts related to fields of knowledge other than Physics. Consequently, articles associated with Biology, Chemistry, and Mathematics were excluded. By applying this first filter, we reduced the analysis corpus to 64 articles, which were organized into folders according to their respective journals. Subsequently, each paper was downloaded.

To facilitate the analysis process, guiding questions were developed to be addressed through the reading and analysis of each of the 64 articles. The purpose of formulating these questions was to

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[1] Available at: https://sucupira.capes.gov.br/sucupira/.
[2] This corresponds to the last available four-year period.
[3] Words used for article search.
[4] It is important to mention that on the website of the journal "A Física na Escola," the search field was limited to articles published in the year 2023. Therefore, we conducted a manual search in each issue published in this journal from 2014 to 2022.

systematize "[...] the analysis of the selected articles, providing greater pragmatism to the investigation, guiding the research, and responding to its specific objectives" (Silva, 2024, p. 26, our translation). In Table 1, we present these questions along with their respective objectives.

Table 1: *Guiding Questions for Article Analysis*

Question of Analysis	Objective
1. What is the nature of the work?	Characterize the work as: theoretical; description of pedagogical methodologies, applications, or software; didactic proposal implemented or not implemented.
2. What is the level of education for which the work was proposed?	Map the educational levels at which the authors propose or use smartphones in Physics Teaching.
3. What Physics topics are addressed in the activity?	Identify which Physics content is most (or least) explored in conjunction with the smartphone.
4. What didactic strategies were integrated with the use of smartphones in the classroom?	Identify which didactic strategies were explored using the smartphone as a resource.
5. What were the objectives of using smartphones in Physics Teaching?	Understand the reasons why the smartphone was used in the classroom.
6. Which smartphone applications were used in the activities?	Identify the main smartphone applications used.
7. What are the potential benefits of using smartphones in Physics Teaching?	Identify the potential benefits attributed to the use of smartphones in Physics Teaching.
8. What are the limitations regarding the use of smartphones in Physics Teaching?	Identify the limitations of using smartphones in Physics Teaching.

As previously mentioned, we employed the categorization method described by Yin (2016) to analyze the data. In the data compilation phase, we read the articles and highlighted text fragments related to the guiding questions. After that, we moved on to the disaggregation phase, where we used Google Sheets to organize the responses along with their corresponding guiding questions. In these sheets, the article titles were arranged in rows, along with their respective "answers" to the guiding questions. To regroup the data, we conducted an inductive thematic analysis, in which the responses to the guiding questions were reread in order to identify patterns among them, with the aim of reorganizing them into categories. This was carried out through the creation of new text documents, intended to organize and synthesize the data to facilitate narrative construction.

During the interpretation phase, we analyzed and interpreted each question and its respective categories individually. This required the creation of new narratives that incorporated initial considerations regarding the interpretations made for each category. In the conclusion phase, we analyzed the ideas generated during the previous stage and wrote a brief text summarizing what each question revealed to us.

It is important to note that after reading all the works, we found that some did not address the proposed questions and, therefore, were not relevant to the aims of this review. Consequently, we narrowed the data analysis to only those works that responded to the guiding questions. This brought us to a total of 51 analyzed articles. Each article was assigned an identification number from 1 to 51, organized in a table, which can be accessed via the link provided in this footnote[5]. The methodological procedures used in the selection of journals and articles are summarized in the diagram represented by Figure 1.

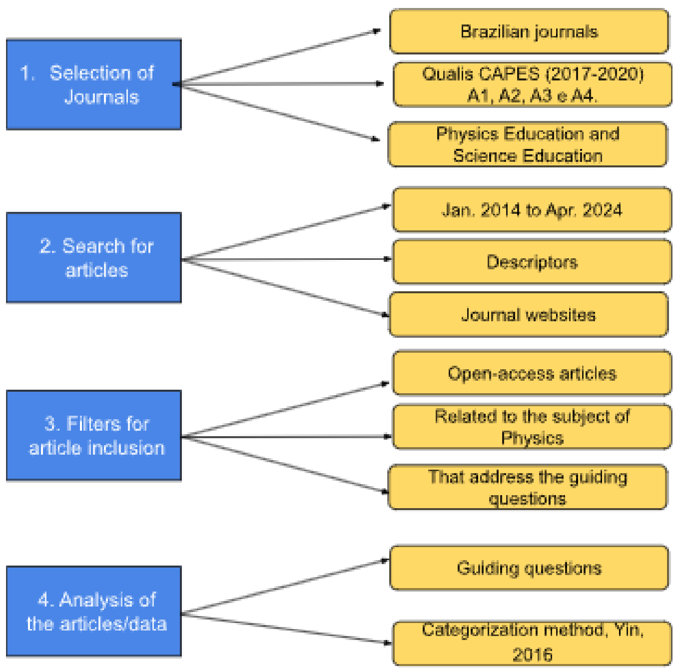

Figure 1: Methodological Procedures Conducted

RESULTS AND DISCUSSIONS

In this section, we present the results derived from the analysis of the selected articles. We observed that the proposals span different educational levels; experimental activities are the main didactic strategy employed; there is a wide variety of applications that can be used; and wave phenomena stand out as the most frequently addressed area of physics when smartphones are utilized. Furthermore, the authors indicate that smartphones: bring classroom activities closer to

[5] Numbering of analyzed articles..pdf

real-life and everyday situations; promote student engagement; make lessons more dynamic and interactive; can be highly distracting; are often restricted by school management; and are not accessible to all students.

We will now discuss each question individually. It is important to note that some articles may appear in more than one category, while others address only a portion of the analysis questions. Additionally, questions 1, 2, 3, 4, and 6 allow for a direct classification of the analyzed articles. Therefore, for these, the process described by Yin (2016) was not necessary, leaving questions 5, 7, and 8. Below is the analysis of each of the guiding questions for this study.

Guiding Question 1: What is the nature of the work?

The results for this question are expressed in Table 2.

Table 2: *Articles by category for guiding question 1*

Nature	Number of Studies	References
Description of Active Methodologies	1	8
Theoretical Study	1	39
Implemented Didactic Proposal	17	2; 5; 6; 11; 12; 13; 15; 19; 20; 21; 23; 24; 26; 29; 37; 49; 50
Unimplemented Didactic Proposal	32	1; 3; 4; 7; 9; 10; 14; 16; 17; 18; 22; 25; 27; 28; 30; 31; 32; 33; 34; 35; 36; 38; 40; 41; 42; 43; 44; 45; 46; 47; 48; 51

As we can see in Table 2, approximately 96% of the analyzed works correspond to activity proposals, whether implemented or not. In this context, it is important to highlight that we consider implemented proposals to be those conducted in the classroom with students. On the other hand, the unimplemented didactic proposals were carried out only as demonstrations, typically in schools or universities. Although these activities produced results, they were not applied in actual student classes. Thus, these activities were classified as unimplemented.

Guiding Question 2: What is the educational level for which the work was proposed?

Table 3 summarizes the results obtained for this research question.

***Table 3**: Articles by category for Question 2*

Level of Education	Number of Studies	Reference
Elementary Education	6	11; 16; 18; 21; 23; 25
High School - EJA[6]	1	37
High School - Regular	28	1; 2; 4; 5; 8; 9; 10; 12; 13; 14; 15; 16; 17; 18; 19; 20; 22; 24; 26; 28; 29; 32; 33; 34; 40; 41; 46; 48
Higher Education	21	6; 8; 9; 15; 17; 22; 28; 30; 33; 34; 35; 36; 40; 41; 42; 43; 44; 45; 46; 47; 50
Not specified	7	3; 7; 27; 31; 38; 39; 49; 51

Through the results shown in Table 3, we identified that most of the analyzed works involving the use of smartphones in education are in the context of high school and higher education. However, what stands out are the works aimed at application in the context of elementary school, as the 9th grade was generally the only time students had contact with Physics. This data is considered relevant and promising, as activities conducted with the use of mobile technologies at this educational level can promote student interest and motivation for experimentation through the educational use of cell phones (VERNIER; DUTRA, 2019).

Thus, we have some indications that the smartphone, as a didactic resource, can be integrated at different educational levels. Even in elementary education, with younger students, the use of this tool can, when implemented appropriately, provide several advantages to the teaching and learning process in Science or Physics. On the other hand, the higher number of published works in high school and higher education indicates that the use of this technological resource has been planned and integrated into school and academic activities, suggesting that the smartphone can be a potential ally in the teaching and learning practices developed in these contexts.

Guiding Question 3: Which topics of Physics were addressed in the activity? With this third question, we sought to observe which Physics content was integrated with the use of smartphones in the analyzed didactic proposals (both implemented and not implemented).

The results obtained are summarized in Table 4.

[6] Adult Education (EJA) is an educational modality aimed at young people, adults, and elderly individuals who did not have access to conventional schooling at the appropriate age. It allows students to resume and complete their studies in a shorter period, thereby enhancing their qualifications for better opportunities in the job market.

Table 4: *Articles by category for Question 3*

Topics in Physics	Number of Studies	Reference
Astronomy	3	7; 25; 27
Kinematics	9	4; 12; 18; 21; 23; 26; 41; 42; 50
Dynamics	8	20; 21; 33; 35; 36; 39; 44; 45
Electromagnetism	1	31
Modern and Contemporary Physics	4	11; 24; 40; 49
Fluids	1	43;
Waves	16	1; 2; 5; 6; 9; 10; 14; 15; 17; 22; 28; 30; 32; 34;46; 47
Optics	8	3; 13; 16; 19; 29; 38; 48; 51

From Table 4, we can see that the most addressed topic was Waves, with the majority of the works related to mechanical waves, especially sound waves. We believe that this topic is the most commonly addressed when it comes to using smartphones because it is simpler to conduct low-cost experiments.

Other topics such as Kinematics, Dynamics, and Optics also stand out and were addressed with relative frequency in the analyzed articles. The wide variety of topics found indicates the diverse possibilities for using smartphones, highlighting their potential applicability in various areas of Physics.

Guiding Question 4: What teaching strategies were integrated with the use of smartphones in the classroom? With this question, we aimed to identify the teaching strategies associated with the educational use of smartphones.

The results obtained are presented in Table 5.

Table 5: *Articles by category for Question 4*

Didactic strategy	Number of Studies	Reference
Experimental Activity	45	1; 2; 3; 4; 6; 7; 9; 10; 11; 12; 13; 14; 15; 16; 17; 18; 19; 20; 22; 23; 24; 25; 26; 27; 28; 30; 31; 32; 33; 34; 35; 36; 38; 39; 41; 42; 43; 44; 45; 46; 47; 48; 49; 50; 51
Theoretical Study	1	40
Active Methodologies	6	5; 8; 21; 23; 37; 29

We noted that the majority of the analyzed works used experimental activities as the didactic strategy associated with the use of smartphones. One reason for this is that smartphones serve as a significant ally as an "alternative to overcome the problems faced by the lack of equipment in Physics laboratories" (Guedes, 2015, p. 1, our translation). Another reason lies in the fact that smartphones now possess a wide array of sensors that can be utilized in various experimental activities (Guedes, 2015; Pereira, 2021; Vieira & Aguiar, 2016; Vieira et al., 2014).

This aligns with the position of Ferreira and Almeida (2022), who assert that an experimental activity in the educational context "[...] should be simply constructed, easy to execute, and capable of clearly demonstrating the physical phenomena involved, ensuring that the measurement is efficient and the analysis as complete as possible" (Ferreira & Almeida, 2022, p. 1, our translation). Thus, we have some indications of why experimental activities are strongly linked to the use of smartphones as a didactic resource.

Some studies also employed the Active Methodology known as Peer Instruction (PI). PI was developed by Erik Mazur in the 1990s at Harvard University (Jardim et al., 2018). In this methodology, unlike the traditional approach, students are the protagonists of the class. The teacher prepares conceptual questions in advance to guide the lesson's development. Based on these questions, students must reflect individually without interacting with each other. After the designated reflection time, they vote on their answers, and the teacher evaluates the responses to determine the next steps of the lesson, taking into account the overall set of answers provided by the students (Jardim et al., 2018).

In this context, evaluating the responses is essential to determine the next steps in the lesson. Ideally, for dialogue to occur effectively and for the methodology to succeed, the percentage of correct answers should fall between 30% and 70%. In this case, students should form groups of two to five individuals, with each member presenting their answers with supporting arguments. The goal of this stage of PI is for students to debate among themselves, using arguments and counterarguments regarding the options they chose in the voting.

In the analyzed studies, smartphones were integrated with Peer Instruction (PI) as a tool for individual student voting. For this purpose, three applications were identified: Plickers, PInApp, and Socrative. According to Kielt et al. (2017), the advantages of using smartphones instead of response cards, known as flashcards, include in the increased speed of voting, data storage and sharing capabilities, and the enhancement of response confidentiality.

Another teaching strategy identified during this review was the use of games in Physics Education. The use of games represents an innovative active methodology for the educational environment, as it allows for the incorporation of a wide variety of elements and techniques found in games that offer challenging and engaging situations (Sales et al., 2017). From the same perspective, Ferreira et al. (2017), in their study involving the use of a game, emphasize that using games from a didactic perspective can play a significant role in students' construction of meaning. Furthermore, the study highlights that when a commercial game is used—that is, one not originally designed for educational purposes—the structure of the activity must be adapted so that students can develop the ability to accurately represent the physical phenomena that can be explored through the game.

Problem-solving was another active methodology identified. 'In general, a situation can be regarded as a problem when it requires a response that cannot be achieved in a straightforward manner through a direct operation' (Pastorio et al., 2017, p. 73). In the study analyzed here, the use of a smartphone application was proposed for solving Mathematics and Physics problems with students in the final years of elementary school. The authors reported that using the app facilitated problem solving and also helped students associate concepts such as distance, time, and speed (Santos et al., 2017).

Through the analysis of this question, we can conclude that various teaching strategies can be developed in conjunction with smartphones, providing evidence of the pedagogical potential of this technological tool in the classroom.

Guiding Question 5: What were the objectives of using smartphones in Physics Teaching? This question made it possible to identify the didactic objectives outlined in the reviewed studies regarding the use of smartphones in the classroom.

The categories developed for this question are identified in Table 6.

Table 6: *Articles by Category for Question 5*

Category	Number of Studies	Reference
Data generation	9	6; 10; 11; 20; 24; 28; 31; 49; 51;
Measurement or Data Collection Instrument	28	1; 2; 4; 6; 7; 9; 10; 14; 15; 16; 18; 22; 23; 25; 27; 28; 30; 31; 32; 35; 39; 40; 42; 43; 46; 47; 48; 50;
Games	2	21; 29;
Graph Plotting	2	30; 51;
Film or Photography Recording	12	3; 12; 13; 17; 19; 26; 33; 34; 36; 41; 44; 45;
Voting System (Peer Instruction)	3	5; 8; 37;
Other	1	38;

As initially expected, the primary purpose of using the smartphone was as a tool for data collection. The smartphone was used to conduct experimental activities in a way that made them more accessible, especially when the school lacked specific laboratory facilities for experimental activities. Smartphones are equipped with various sensors that can be used to collect experimental data, which can be utilized in practical activities for educational purposes.

The results presented in Table 6 also demonstrate that the smartphone was used as a source generator in experimental activities. In this context, the device served as a light source, a sound frequency generator, or a signal generator. For this category, few authors questioned the effectiveness (or lack thereof) of the smartphone as a source. For example, the study by Quinquiolo et al (2019) highlighted a difficulty when attempting to use the phone's flashlight together with a filter to simulate black light emission. According to them: “The phone's flashlight is composed of an LED light that does not emit ultraviolet radiation. When we apply the permanent marker coloration, it resembles black light but does not produce the same effect” (Quinquiolo et al., p. 53, 2019, our translation).

Another purpose identified was image capture, particularly for video recording. In these cases, the smartphone was used for filming movements, which are then analyzed using specific software. The use of the smartphone was only a part of the overall activity, as the entire process required additional technological resources. The studies by Reis (2017), Silva & Sampaio (2020), Marculino et al. (2019), Jesus and Sasaki (2014), Jesus & Sasaki (2016), and Júnior & Aranha (2015) are examples that illustrate this use of smartphones.

In addition to these objectives, other less frequent uses were identified. Among the less common ones, we can mention the use of games for educational purposes and the use of voting systems in the Peer Instruction methodology, as discussed in question 4. We also found the use of smartphones for real-time graph plotting, as well as transforming the device into a webcam, using the screen as a Brewster stereoscope, and utilizing the camera for color evaluation through an application.

From this analysis, we can infer that there are many educational purposes for which smartphones can be useful, especially in the context of experimental activities. The studies analyzed here indicate that, generally and for educational purposes, smartphones can be used as a data collection tool through their sensors and installed applications. Additionally, these devices can serve as a generating source in certain experimental activities, particularly those requiring sources of sound frequency and light. Moreover, when it comes to analyzing the movement of a body, video recording using a smartphone is an excellent low-cost alternative, as it eliminates the need for an expensive commercial camera. Furthermore, when the use of games in the educational environment is desired, the smartphone emerges as the primary option for this purpose.

Guiding Question 6: Which smartphone applications were used in the activities? Through this question, we were able to map the applications utilized in studies involving the use of smartphones in educational activities.

The results are presented in the graph shown in Figure 2.

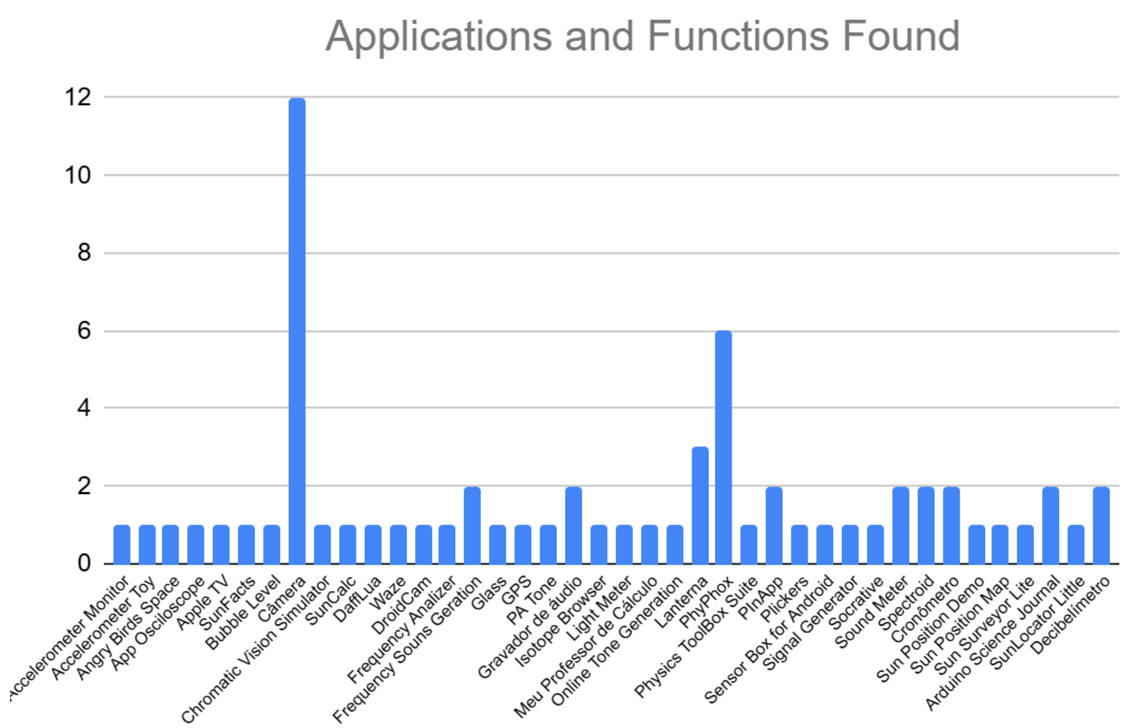

Figure 2: Graph Related to the Applications/Functions Found in the Articles

From the analysis, we identified a total of 40 applications used in the studies. Among the functions, the most frequently used was the camera (n=12). Most of the studies that employed this function used it to record movements in video for later analysis. Other functions utilized included: GPS (n=1); stopwatch (n=2); flashlight (n=3); and audio recorder (n=2).

Among the applications, we found a wide variety. The following stood out: PhyPhox (n=6); PInApp (n=2); Sound Meter (n=2); Spectroid (n=2); Arduino Science Journal (n=2); Decibelímetro (n=2); and Frequency Sounds Generator (n=2). Among them, PhyPhox was the most frequently used application in the analyzed studies. We believe this is due to the fact that the app is free and available on the two major download platforms (Apple Store and Play Store), in addition to enabling experiments to be conducted in various areas of Physics.

Pereira (2021) also utilized the aforementioned application to obtain angular velocity by taking measurements with the smartphone's gyroscope sensor. The author emphasizes that "The free Phyphox application added another function to smartphones; this application accesses the various sensors of the smartphone and transforms it into a portable physics laboratory" (Pereira, p. 2, 2021, our translation).

Santos & Laia (2023), in turn, also used the application as a lux meter in their experiment on Malus's Law. They highlight that "The use of the PhyPhox application allows for quick acquisition of results and facilitates data visualization during and after the experiment" (Santos & Laia, p. 8, 2023, our translation).

With this question, we were able to visualize a considerable range of application options and functions that smartphones offer. In this regard, Bedaque & Bretones (2019) state that this can already be a motivating factor for students. "The choice of the most suitable application is in itself a curious research topic, which will certainly interest students" (Bedaque & Bretones, p. 44, 2019, our translation).

Guiding Question 7: What limitations did the authors identify regarding the use of smartphones in Physics Teaching? This question allowed us to organize categories concerning the main limitations of using smartphones in EF. Here, it is important to highlight that, in most of the analyzed studies, the authors did not indicate the limitations of using smartphones in the educational environment for didactic purposes.

However, for the studies that presented this data, we were able to organize them into the categories described in Table 7.

Table 7: *Articles by Category for Question 7*

Limitations or Challenges	Number of Studies	References
Technical Obstacles of Sensors	13	2; 7; 9; 11; 14; 18; 31; 32; 39; 42; 43; 46; 47
Attention to Experimental Setup	5	10; 22; 28; 45; 47
Lack of Infrastructure	3	5; 23; 37
Distracts Students	3	9; 20; 23
Resistance from Teachers and Administrators	5	2; 9; 20; 29; 50

The first category highlights criticisms regarding the smartphone sensors. Like any experimental activity, measuring instruments must be calibrated, their handling should be done with care and skill, and the environment should be structured to minimize the interference of external factors that may influence the results. When using the smartphone as a measuring instrument, this is also a relevant consideration.

Some of the analyzed authors pointed out the inaccuracy of the sensors, particularly due to the differences between the smartphone models used. For example, in the proposal by Marranghello et al. (2020), two models of smartphones showed significant discrepancies in light intensity measurements. Similarly, in measurements of sound wave frequency, Rossini et al. (2021, p. 5, our translation) state that "[...] the same application may provide different values for the same frequency, depending on the microphone model of each mobile device.".

Additionally, other authors reported the unreliability of smartphones compared to professional measurement equipment. Bedaque and Bretones (2019), although they did not compare the measurements of smartphones with professional instruments, emphasize that smartphones are likely to perform poorly in such comparisons. For instance, we can highlight the work of Sampaio et al. (2022, p. 4, our translation), which states, "Due to external noise and the sensitivity of the audio sensor of the smartphone used, beyond the 5th harmonic, the peaks become less perceptible, and essentially what remains are noises." In this regard, Pereira et al. (2022) point out a limitation regarding the smartphone's ability to measure sound wave frequencies: "Smartphones commonly have difficulty capturing frequencies above 4 kHz. Due to this limitation, it is recommended that the source frequency be 3 kHz" (Pereira et al., p. 2, 2022, our translation).

Still within this category, the works of Rodrigues and Arnold (2022) and Soares (2023) indicated that the lack of sensors such as barometers in most smartphone models hinders the execution of certain experiments, particularly those related to determining altitude based on local atmospheric pressure.

Related to the second category, titled Attention to Experimental Setup, as with any experimental activity, the setup and operation of the apparatus used are factors that influence the final outcome of the activity. In the case of using smartphones in experimental activities, certain precautions must be taken, particularly regarding the direction in which the device is oriented. For example, when the experimental activity involves capturing sound, noise, or sound frequency, care must be taken to point the microphone toward the source of the sound, as noted by Pontes (2023) and Rossini et al. (2021). Another consideration, as highlighted by Rossini et al. (2023), is to operate the stopwatch carefully when time measurement is needed, in order to minimize experimental error.

The third category revealed that using smartphones in classes can be problematic if not all students have access to the device or if the school does not have Wi-Fi networks available in the classrooms. Although these are relevant issues, they can be overcome, as in the majority of the analyzed studies, individual access to smartphones smartphones was not necessary. Most activities were conducted in groups and emphasized collaboration.

However, this factor can be significant if the intention is to use smartphones as a voting system in the Peer Instruction methodology. In this case, it will be essential for each student to have a device to cast their votes individually. On the other hand, we found that the applications used, once installed, do not require internet access to perform measurements. Therefore, even if the school does not have Wi-Fi networks in the classrooms, students can install the application in a location where they can connect to the network, as long as do not have mobile internet service on their smartphones.

The penultimate category is related to the possibility of smartphones contributing to students' distraction when they have the freedom to use the device in the classroom. Although few studies highlight this aspect, it is evident that for students to use their phones appropriately in class, they need to view the device as a tool that can be employed not only for entertainment, such as social media, but also for recognizing its advantages in educational activities.

It is worth noting that the analyzed studies indicate that using this device can bring a certain level of motivation and, consequently, greater student engagement in activities. However, when introducing the device for classroom activities, the teacher must be aware that students may disengage from the proposed activity and use their phones for purposes unrelated to the lesson. To prevent this, the activity must be well thought out and carefully planned.

The fifth and final category refers to the resistance from some teachers or school management, who hinder the use of smartphones in the classroom. This resistance from teachers often arises from a lack of confidence in using technological resources. This was the case with Pereira et al. (2022), who state that “[...] many teachers are reluctant to use this technology due to insecurity regarding the new” (Pereira et al., p. 1, 2022, our translation).

This situation may stem from a lack of training and knowledge on how to work with Information and Communication Technologies (ICT) in Physical Education. After all, some teachers did not encounter this topic during their undergraduate studies and have not had the opportunity to participate in ongoing training courses on this subject (Bedaque & Bretones 2019).

On the other hand, school management may not be supportive of using this tool in the classroom. The work of Ferreira et al. (2020) clearly illustrates this fact, as they developed a Potentially Significant Teaching Unit to study Geometric Optics using game-based learning. The authors claim that at a certain point, the school halted the use of this didactic strategy.

Through the analysis of this question, we elucidated the main challenges identified in the reviewed articles regarding the use of this mobile technology in Physical Education. We can observe that few articles mention the challenges and limitations, which is a point that should be questioned, as discussing these negative aspects is also essential for improving and developing future works or proposals. For example, the teacher can utilize the differences in smartphone measurements to discuss experimental errors related to the equipment used, as highlighted by Marranghello et al. (2020): “the teacher can take the opportunity to discuss with students the dependence of scientific analyses on measuring equipment” (Marranghello et al., p. 12, 2020, our translation).

Moreover, we can conclude that, despite the difficulties surrounding its use, the smartphone can be utilized as a didactic resource. In this regard, we also support the notion that teachers should have exposure to digital technologies during their training process. Additionally, it is essential to plan ongoing professional development actions to minimize training gaps among educators.

Guiding Question 8: What potentialities did the authors identify in the use of smartphones in Physics Teaching? With this question, we were able to illustrate the main potentialities of using smartphones in Physics Teaching.

The results are presented in the categories shown in Table 8.

Table 8: *Articles by Category for Question 8*

Potentialities	Number of Studies	References
Connection of the lesson with everyday and real-life situations.	13	2; 3; 9; 11; 18; 20; 21; 22; 23; 36; 41; 43; 50
Good accuracy of the device as a data collector or generator.	13	1; 6; 10; 14; 18; 25; 31; 32; 35; 39; 41; 43; 51

Democratization of experimental activities.	28	1; 9; 10; 11; 12; 14; 16; 17; 18; 20; 21; 22; 23; 28; 31; 32; 33; 35; 39; 40; 42; 43; 44; 45; 46; 47; 48; 51
Student engagement.	20	2; 3; 6; 9; 11; 12; 14; 16; 17; 18; 19; 20; 21; 22; 23; 29; 37; 46; 48; 50
Stimulates interdisciplinarity.	3	6; 12; 21
Facilitates learning.	8	9; 12; 19; 20; 21; 23; 29; 47
Energizes and enhances lessons, serving as an alternative to traditional teaching methodologies.	9	9; 12; 14; 20; 23; 36; 37; 42; 46

The first category highlights the success in addressing one of the current problems in Physical Education: the lack of connection between lessons and the real-life situations of students. Through the analysis of the articles, we found several studies that emphasize this aspect as a positive feature of smartphones. For instance, we can highlight the work of Vieira & Aguiar (2016), who clearly express this point.

> "*As most students carry a smartphone in their pocket, they can use the device's resources to analyze phenomena from their daily lives, establishing the essential relationship between the physics studied in the classroom and everyday experiences*" (Vieira & Aguiar, p. 9, 2016, our translation).

> "*If well explored, the possibility for students to use their own cell phones to investigate physical phenomena opens up many opportunities for action, even outside the school, bringing everyday situations closer to the topics addressed in the classroom*" (Vieira & Aguiar, p. 14, 2016, our translation).

In the second category, the authors indicate that the experimental functions of the smartphones used in the experiments have adequate precision for the educational objectives that the activity aims to achieve. Soares (2023) states that the accuracy of the sensors used "[...] is equivalent to that of devices used for recreation, and is therefore applicable for data acquisition in educational contexts" (Soares, p. 2, 2023, our translation).

The third category reveals that, with the integration of smartphones into the planning of activities, there is a democratization of experimental work. In our study, we have addressed the lack of laboratories in schools and, in conjunction with this, the justification for not conducting experimental activities. We also emphasized the fact that mobile phones serve as an alternative for conducting experiments. Now, upon analyzing the selected articles, we found authors who have applied this perspective and corroborated it, as well as others who assert the possibility of expanding the school's environment, claiming that with this resource, students can even conduct experiments in non-school settings. (Garcia *et al,* 2023; Pereira *et al,* 2022).

Admiral (2020) also highlights this point.

> "*In a scenario where there is a potential lack of physical space for a laboratory, or, when this is not the case, a lack of specific physics laboratory equipment, we believe that using this equipment as a teaching strategy can provide a wide range of possibilities for educational activities."* (Admiral, p. 98, 2020, our translation).

The category related to student engagement indicates a potential way to address one of the problems in Physics Teaching mentioned in the introduction of this work: the lack of student interest in the class and in Physics Teaching. This student engagement in activities proposed by the teacher was consistently observed in the studies analyzed here. Studies such as those by Vieira & Aguiar (2016), Szigety et al. (2020), and Santos et al. (2017) are some examples that support this result.

> "*The use of a device that is part of everyday life provides students with a familiar reference, capable of mediating their participation in didactic experiments. This mediation not only facilitates the execution of the activities proposed by the teacher; it also encourages the development of new investigative actions by the students, such as proposing experiments that extend the original practical activity*." (Vieira & Aguiar, 2016, p. 9, our translation).

One of the most fundamental categories we identified indicated that using smartphones in class facilitated student learning. Anjos et al. (2016), who used electronic games to study concepts of kinematics and dynamics, observed that...

> *"[...] in the subsequent virtual activities, the students assimilated the concepts of projectiles, movements, and different angles well, based on what had been covered during these playful activities, demonstrating through explanations and the handling of objects. [...] This independent creation can be considered a transformation of the acquired knowledge, which is evidence of Ausubelian Meaningful Learning*." (Anjos et al., 2016, p. 134, our translation).

Souza et al. (2017) emphasize

> "*The results demonstrated that technology was an ally in learning the various concepts of speed addressed in physics. The use of the application not only facilitated the resolution of the problems posed during practical classes but also enabled the association of key concepts such as distance, time, and speed. Moreover, the use of mobile technologies contributed to increased motivation and student engagement during classes, leading to improved understanding of the scientific concepts covered*." (Souza et al., 2017, p. 209, our translation).

Ferreira et al. (2020) state that the activities conducted revealed necessary changes in the cognitive structure of the students and helped in the development of meaningful learning. In turn, Rossini et al. (2022) conclude their study by stating that using smartphones in experimental activities provides playful elements. Additionally, employing these elements of multiple representations in the activities helps correlate concepts, generating essential subsumers for meaningful learning.

Thus, we find that these studies point to the development of students' learning in Physics and Science through the use of smartphones in the activities conducted. In particular, there are indications that the Theory of Meaningful Learning (Ausubel, 1968) can be extensively explored and developed when articulated with DICT.

The last category that emerged from our analysis relates to the advantages associated with the development of lessons. In this category, the studies we analyzed indicate that using smartphones as a resource promotes time savings, making the class more dynamic and of higher quality, as well as allowing for the use of pedagogical methodologies different from traditional ones.

Pereira et al. (2022) state that "if we consider the current landscape of public education networks, the experimental use of cell phones improves the dynamics and quality of physics classes" (Pereira et al., 2022, p. 5, our translation).

A relevant piece of evidence regarding the improvement of the lesson when using this resource was observed in the work of Reis (2017), in which one of the students in the class where the methodology was applied reported that: “The class is more dynamic, making it easier to keep up…” (Reis, 2017, p. 49, our translation).

Vieira & Aguiar (2016) found that:

> *“[...] smartphones can enable the development of didactic experiments in which data collection and presentation are carried out with extreme speed and simplicity, allowing for immediate discussion and interpretation of the results obtained and facilitating the integration of practical activities into classes that would otherwise be purely expository*.” (Vieira & Aguiar, 2016, p. 14, our translation)

Furthermore, in this regard, Rossini et al. (2021) conclude their study by corroborating our statements about this last category, noting that young students are willing to handle the device, which provides an effective means of connecting the traditional language of graphs and tables with the more interactive language of the electronic environment.

Through this analysis, we were able to map the potentials identified by the authors of the reviewed studies regarding smartphones in Physics Teaching, translated through the categories we discussed earlier. We also highlight some possibilities that the didactic use of smartphones can bring to the teaching and learning process in the subject of Physics. For example: contributions to enhancing student learning; an alternative to didactic laboratories or the lack thereof; making lessons more dynamic and optimizing classroom time. Furthermore, we emphasize that this practice can generate curiosity and interest in students, making them more participative in the activities developed in the classroom.

FINAL CONSIDERATIONS

This literature review aimed to survey articles published in Brazilian journals of Physics Teaching and Science Teaching with the highest ratings in Qualis CAPES (2017-2020) over the past ten years, focusing on those that discuss or utilize smartphones as a didactic resource in the teaching and learning process of Physics.

We found 64 works, of which 51 were selected to comprise the corpus of this literature review. For quantification purposes, we can highlight that of the 51 analyzed articles, approximately 88% were published in the journals “A Física na Escola” and “Revista Brasileira de Ensino de Física.” The remaining 12% of the other articles are distributed among the other five journals.

In this context, some considerations must be made, including the educational levels in which the use of smartphones was proposed or implemented. Our results indicate that this technological resource has been utilized at different levels, starting from the final years of elementary education, through high school, where most of the studies are focused, and extending to higher education, such as undergraduate courses in Physics, for example.

The results also indicate that experimental activities are the main didactic strategy associated with the use of smartphones. We hypothesize that this is due to the various capabilities that smartphones offer. Additionally, there is evidence that this tool has the potential to promote the democratization of experimental activities, which can be conducted without large equipment or specific laboratories. This enables the execution of such activities even outside of formal lab settings. Furthermore, students can even carry out or redo experimental activities in a home environment.

Another aspect raised by our work is the variety of Physics content that can be addressed through the didactic use of smartphones. Although the field of Wave Phenomena has stood out, other themes have also been explored, demonstrating the versatility of this technological resource for teaching purposes.

In parallel to this, we also found a considerable diversity of functions and smartphone applications that were used in the studies we reviewed. This indicates the potential applicability of this tool in various experiments.

Among the positive aspects regarding the didactic use of smartphones, we highlight: (i) the connection of lessons with everyday and real-life situations; (ii) the reliability of the device as a data generator or collector; (iii) student engagement in the proposed activities, facilitating their learning; and (iv) improvement in the dynamics and quality of classes. Additionally, it democratizes experimental activities, as mentioned earlier, enables opportunities for interdisciplinarity, and optimizes classroom time.

On the other hand, when we consider the negative aspects, we can highlight that the smartphone (i) has some technical obstacles related to the sensors used for data collection; (ii) requires careful attention when operating the device for conducting experimental activities; (iii) is not accessible to all students; (iv) when improperly used and mediated by the teacher, it can become highly distracting; and (v) there is some resistance from teachers or school management.

In summary, we believe that this literature review achieved its proposed objectives and provides evidence that smartphones are a powerful and dynamic digital resource with significant potential for use in the educational sphere. However, it is necessary for schools to become more flexible in incorporating alternative practices to traditional teaching methods, as well as for teachers to receive adequate training to plan the effective use of this device, exploring it in the best possible way.

Furthermore, we believe that this study has provided evidence of how smartphones are being used in Physics classes, highlighting the main strengths and limitations of this tool for educational purposes. Finally, we hope that this Systematic Literature Review (SLR) may serve as a guide for future studies, as well as for teachers, academics, and researchers interested in this topic who view smartphones as potential allies in promoting the quality of teaching and learning processes in the field of Natural Sciences, particularly within the discipline of Physics. We also emphasize that this is an initial work, which will form part of a master's dissertation on the use of smartphones as a teaching resource in the Brazilian context. However, in the future, we intend to expand the discussion to the international context.

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